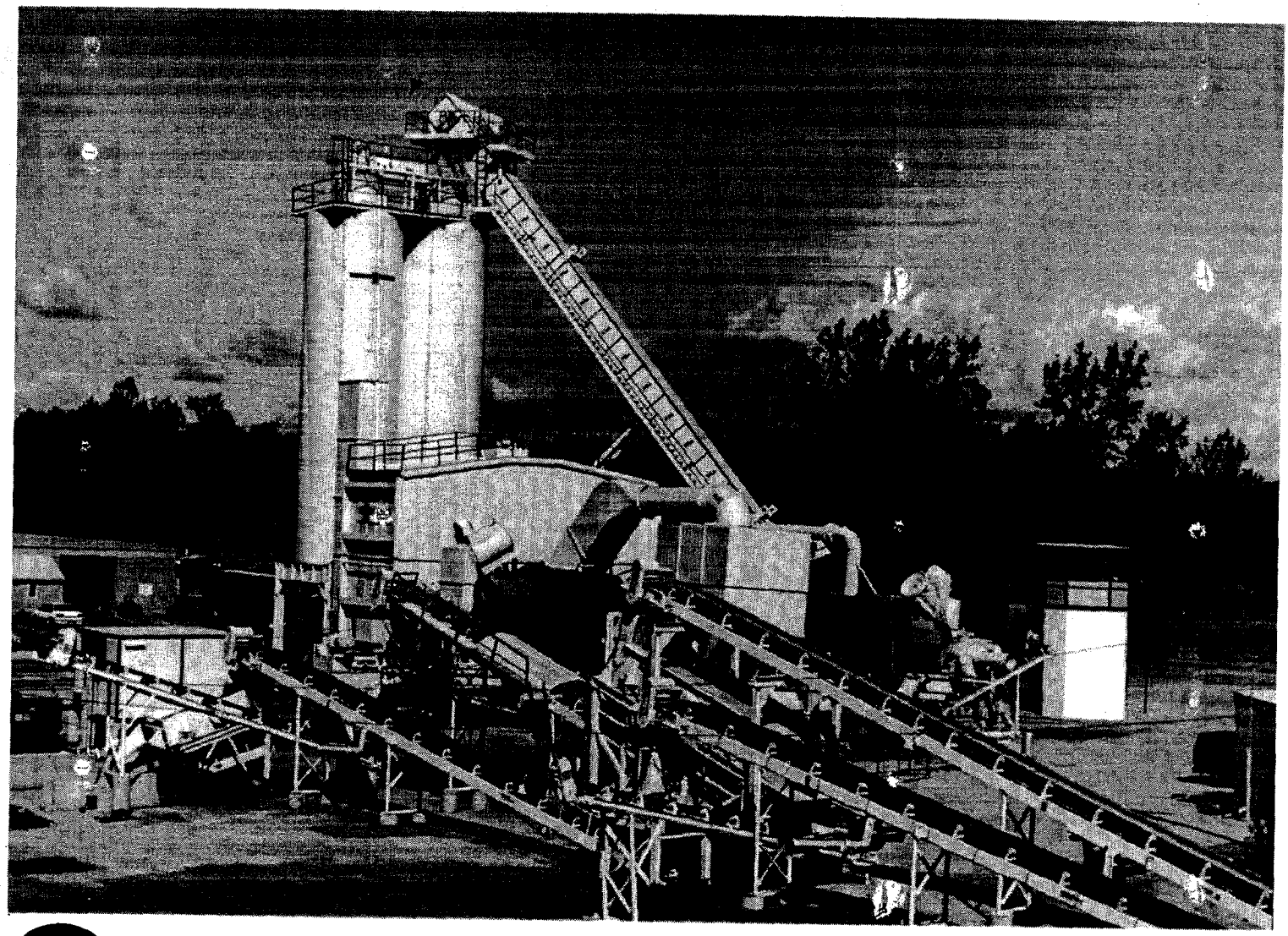
Publication No. FHWA-SA-98-054

U.S. Department
of Transportation

**Federal Highway
Administration**

December 1997

# Pavement Recycling Guidelines for State and Local Governments



National Center for Asphalt Technology
211 Ramsay Hall
AUBURN UNIVERSITY, AL 36849-5354

## Participant's Notebook

# 2-DAY WORKSHOP COURSE ON PAVEMENT RECYCLING

| Session | Chapter | Topic | No. of Slides | Start Time | End Time | Alloted Time (Hours) |
|---|---|---|---|---|---|---|
| DAY ONE | | | | | | |
| | | Introduction | | 1:00 pm | 1:15 pm | ¼ |
| 1 | 1 | Introduction to Pavement Recycling | 27 | 1:15 pm | 2:00 pm | 3/4 (5 min discussion at end) |
| 2 | 2 | Performance of Recycled Mixes | 39 | 2:00 pm | 3:00 pm | 1 (5 min discussion at end) |
| | | BREAK | | 3:00 pm | 3:15 pm | ¼ |
| 3 | 3 | Selection of Pavement for Recycling and Recycling Strategies | 51 | 3:15 pm | 4:45 pm | 1½ (15 min discussion & some discussion during presentation) |
| 4 | 4 | Economics of Recycling | 27 | 4:45 pm | 5:30 pm | 3/4 (15 min discussion) |
| DAY TWO | | | | | | |
| 5 | 5 | Hot Mix Asphalt Recycling (Batch Plant) (Construction Methods and Equipment) | 58 | 8:00 am | 9:30 am | 1½ (5 min discussion) |
| 6 | 6 | Hot Mix Recycling (Drum Plant) (Construction Methods and Equipment) | 31 | 9:30 am | 10:30 am | 1 (15 min discussion) |
| | | BREAK | | 10:30 am | 10:45 am | ¼ |
| 7 | 8 | Hot Mix Asphalt Recycling (Case Histories & QC/QA) | 38 | 10:45 am | 11:45 am | 1 (5 min discussion) |
| | | LUNCH | | 11:45 am | 12:45 pm | 1 |
| 8 | 9 | Hot In-Place Recycling (Construction Methods & Equipment) | 45 | 12:45 pm | 2:00 pm | 1¼ (5 min discussion) |
| 9 | 11 | Hot In-Place Recycling (Case Histories & QC/QA) | 46 | 2:00 pm | 3:15 pm | 1¼ (5 min discussion) |
| | | BREAK | | 3:15 pm | 3:30 pm | ¼ |
| 10 | 12 | Cold Mix Asphalt Recycling (Central Plant) (Construction Methods & Equipment) | 27 | 3:30 pm | 4:15 pm | 3/4 (5 min discussion) |
| 11 | 13 | Cold Mix Asphalt Recycling (In-Place) (Construction Methods & Equipment) | 37 | 4:15 pm | 5:15 pm | 1 (5 min discussion) |
| DAY THREE | | | | | | |
| 12 | 15 | Cold-Mix Asphalt Recycling (Case Histories & QC/QA) | 57 | 8:00 am | 9:30 am | 1½ (5 min discussion) |
| 13 | 16 | Full Depth Reclamation (Construction Methods & Equipment) | 39 | 9:30 am | 10:30 am | 1 (5 min discussion) |
| | | BREAK | | 10:30 am | 10:45 am | ¼ |
| 14 | 17 | Full Depth Reclamation (Case Histories and QC/QA) | 40 | 10:45 am | 11:45 am | 1 (5 min discussion) |
| | | General Discussion | | 11:45 am | 12:00 pm | ¼ |

Slide 1

# Introduction to Asphalt Pavement Recycling

Slide 2

## Advantages

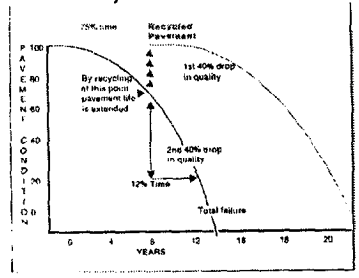
- Reduced Cost of Construction
- Conservation of Aggregate and Binders
- Preservation of Existing Pavement Geometrics
- Preservation of Environment
- Conservation of Energy
- Less User Delay

Slide 3

Recycling is One of the Various Rehabilitation Alternatives

Slide 4

## Why Rehabilitate?




Slide 5

## Why Rehabilitate ?

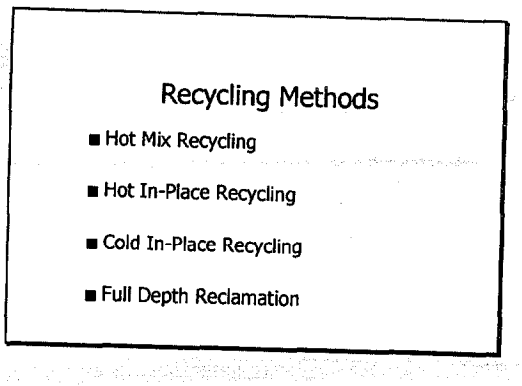
- Inadequate Ride Quality
- Excessive Pavement Distress
- Reduced Surface Friction

Slide 6

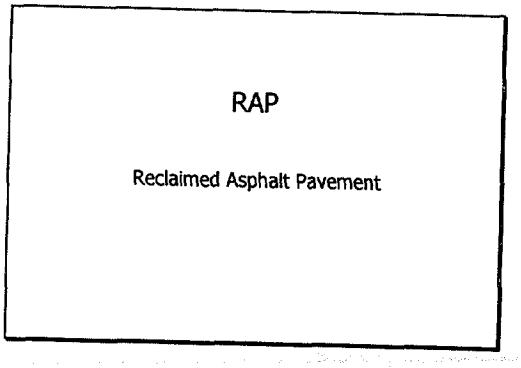
## Why Rehabilitate ? (Continued)

- Excessive Maintenance Requirement
- Unacceptable User Costs
- Inadequate Structural Capacity for Planned Use or Projected Traffic Volumes

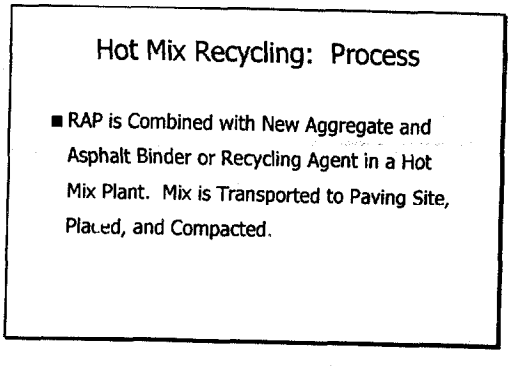
Slide 7




Slide 8




Slide 9



Slide 10

**Hot Mix Recycling in a Drum Mix Plant**

Slide 11

## Hot In-Place Recycling: Process

- Existing Asphalt Surface is Heated, Scarified to a Depth from 20 to 40 mm, Scarified Material Combined with Aggregate and/or Asphalt Binder and/or Recycling Agent and Compacted. New Overlay may or may not be Provided.

Slide 12

**Hot In-Place Recycling: Heater Scarification**

Slide 13


Slide 14


Slide 15

## Cold In-Place Recycling: Process

- Existing Asphalt Pavement Milled (75 to 100 mm Depth), RAP Reduced if Needed, Mixed with Recycling Agent, Placed, and Compacted.

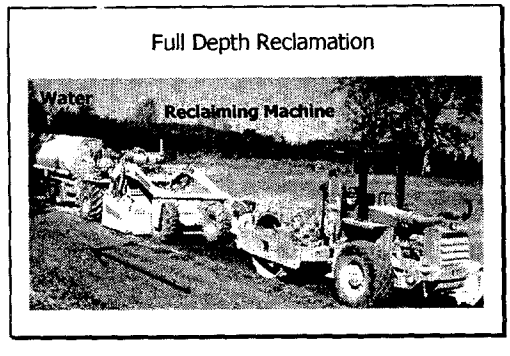
Slide 16


Slide 17

## Full Depth Reclamation: Process

- All HMA Layers and Predetermined Thickness of Underlying Material Pulverized, Stabilized with Additives, Shaped, and Compacted. A Surface Course is Applied.

Slide 18



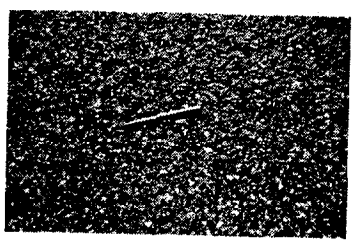
Slide 19

## Primary Distress

- Surface
- Deformation
- Cracking

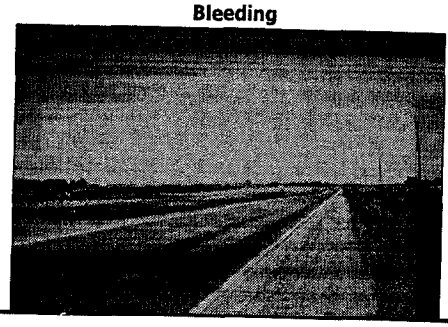
Slide 20

Raveling

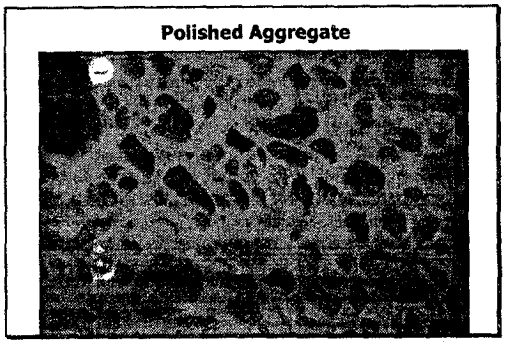


Slide 21

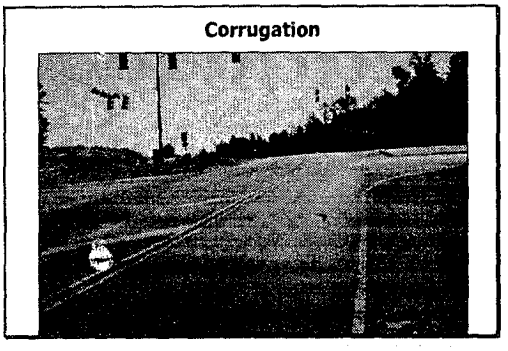
**Bleeding**



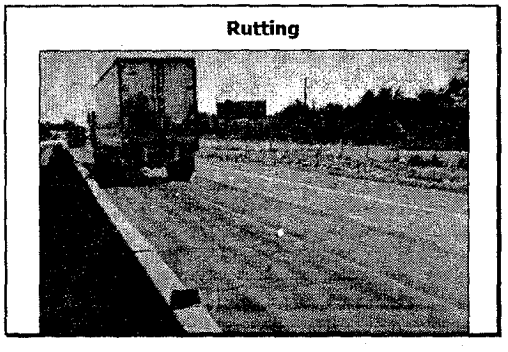
Slide 22




Slide 23

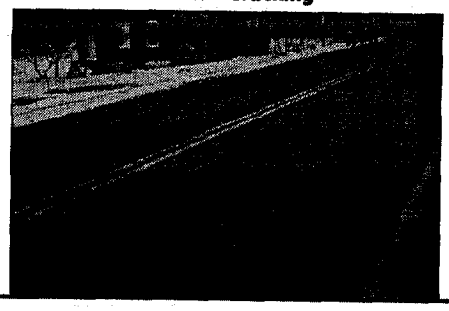



Slide 24



Slide 25

**Thermal Cracking**



Slide 26

## Summary

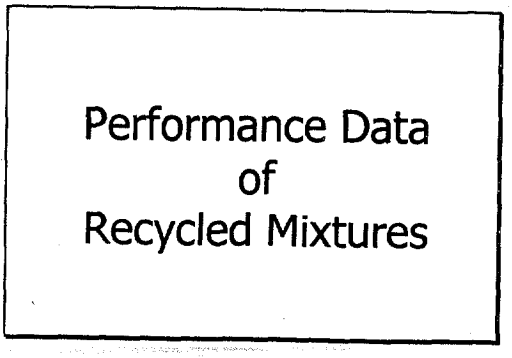
Recycling Techniques are Available to Address Specific Pavement Distress and/or Pavement Structural Requirement

Slide 27

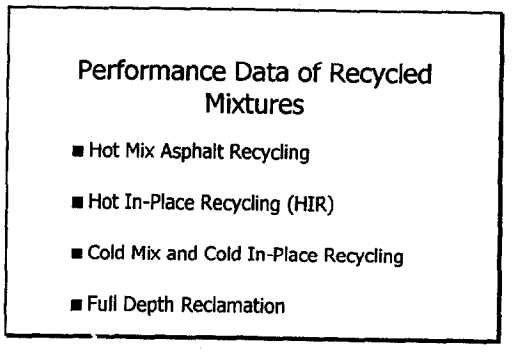
**Introduction to Asphalt Pavement Recycling**

**???**

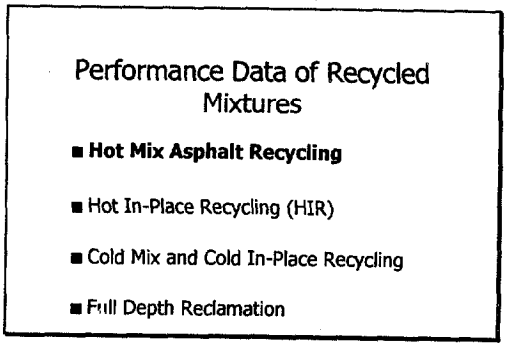
Slide 1




Slide 2




Slide 3



Slide 4

## Hot Mix Asphalt Recycling

- Used Routinely, No Longer Experimental
- Has Performed as Good as Conventional Pavements

Slide 5

## Florida

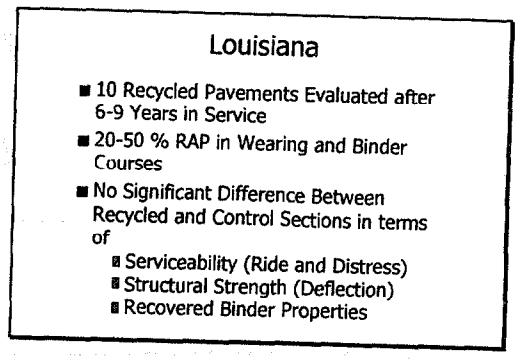
- Milling and Hot Mix Recycling Standard Process
- Reflective Cracks Removed
- Comprehensive Specification, Sampling and Testing Program
- Recycled Binder Tested During Production

Slide 6

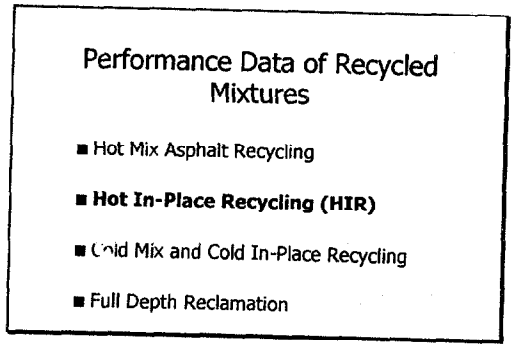
## Georgia

- Comparative Evaluation of 5 Projects Containing Recycled and Control Wearing Course
- RAP 25% (Range: 10% - 40%)
- No Significant Rutting, Raveling and Fatigue Cracking
- Cores Obtained for Testing

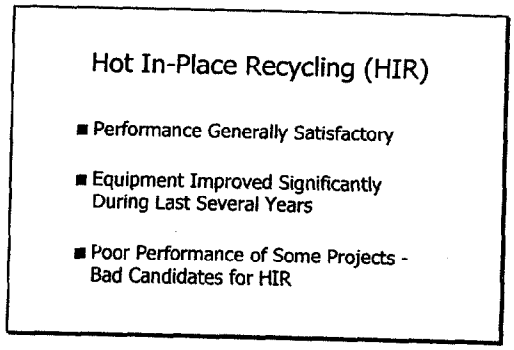
Slide 7




Slide 8




Slide 9



Slide 10

## Canada

- 10 HIR Projects Evaluated in Alberta
- 50 mm HIR - One Pass of Recycling Train
- Visual Condition Survey
  - Reflective Cracks Only
  - Rut Depth 3-7 mm
- Field Cores
  - No Significant Aging of Binder in 6 Years

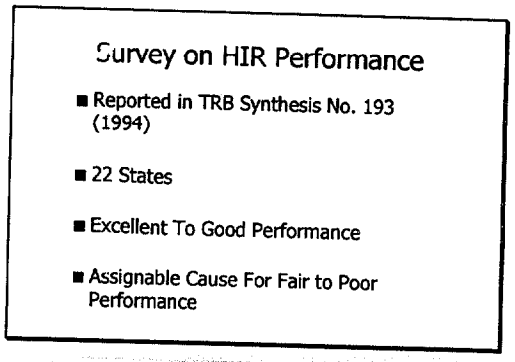
Slide 11

Pavement before Recycling in Canada

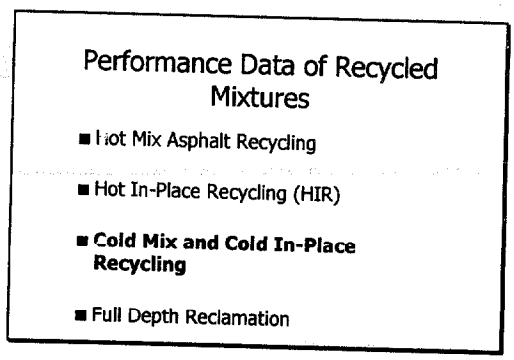
Slide 12

Recycled (HIR) Pavement in Canada

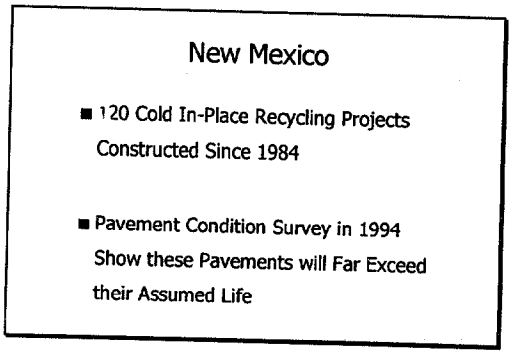
Slide 13




Slide 14




Slide 15



Slide 16

## Performance of CIR Pavements in New Mexico

| % of Projects | Average PCI | Age (Year) | Traffic, AADT (1995) |
|---|---|---|---|
| 91 | 785 (excellent) | 4-12 | 300-10,000 |
| 9 | 54-85 | | |

Slide 17

## Rural Road, New York

Slide 18

View before Recycling

Slide 19

View after Recycling and Application of Hot Mix Overlay

Slide 20

Rural Road, New York

Slide 21

View before Recycling

Slide 22

View after Recycling

Slide 23

## Oregon

- 52 Cold In-Place Recycling Projects Evaluated in 1986
- Traffic Volumes Ranged From Low to High
- 47 Projects: Good Performance
- 5 Projects: Poor Performance Attributed to Too Much Recycling Agent Placing Wearing Course Too Soon
- Major Improvement in Ride Quality

Slide 24

## Pennsylvania

- Over 90 Cold In-Place Recycling Projects Constructed
- Performance Very Satisfactory
- Poor Performance on Some Projects Attributed to Inadequate Wearing Course (For Example, Single Seal Coat Only)

Slide 25

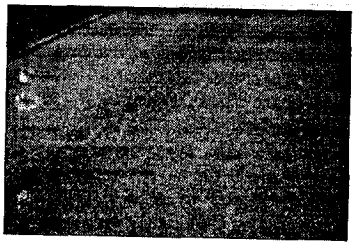
Susquehanna County,
Pennsylvania

Slide 26

View before Recycling

Slide 27

View after Recycling



Slide 28

Schuylkill County, Pennsylvania

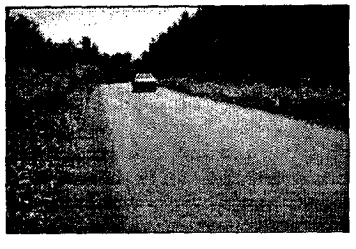
1983

Slide 29

View before Recycling

Slide 30

View after Recycling (Good Condition)



Slide 31

View after Recycling (Poor Condition)

Slide 32

## Performance Data of Recycled Mixtures

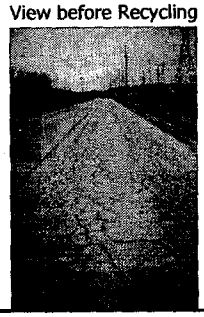
- Hot Mix Asphalt Recycling
- Hot In-Place Recycling (HIPR)
- Cold Mix and Cold In-Place Recycling
- **Full Depth Reclamation**

Slide 33

Rural Road, New Hampshire

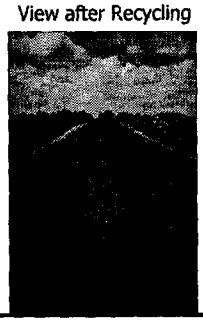
Slide 34

View before Recycling



Slide 35

View after Recycling

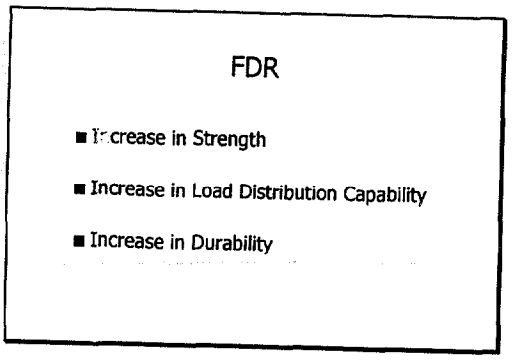


Slide 36

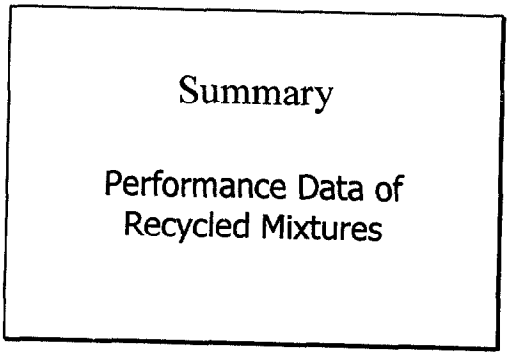
FDR

- Long Term Performance Data Not Available
- Good Experience Reported by Several Agencies

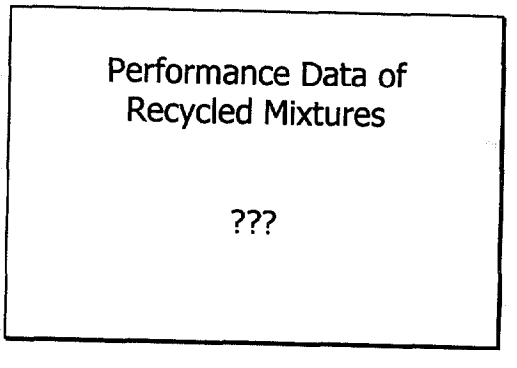
Slide 37



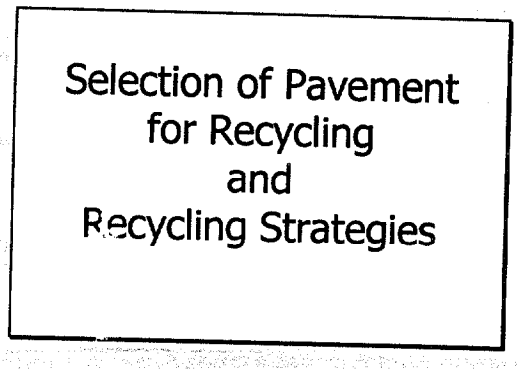

Slide 38



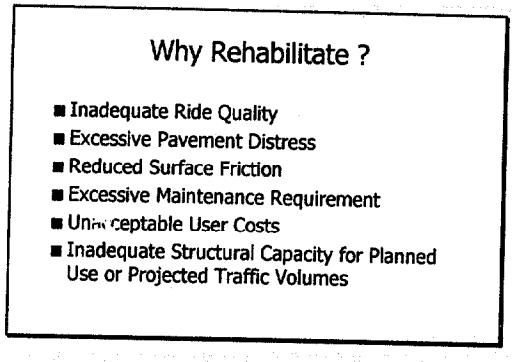

Slide 39



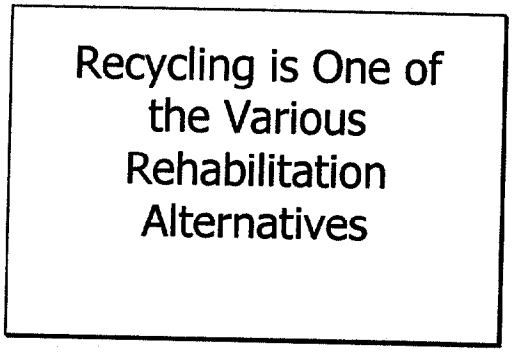
Slide 1



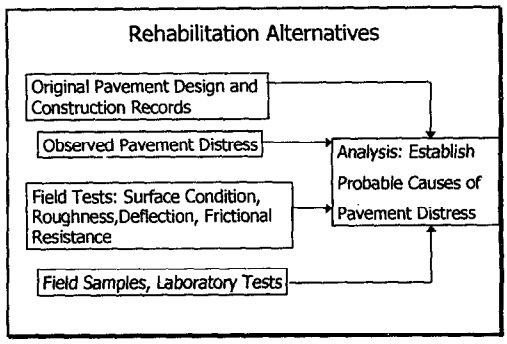

Slide 2



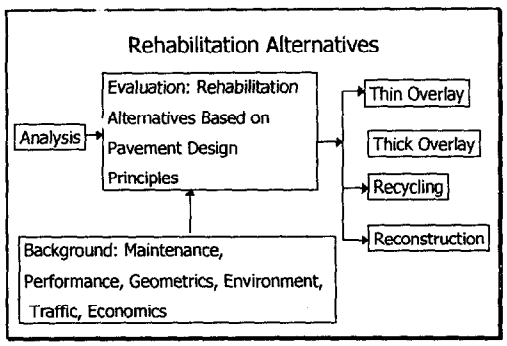

Slide 3



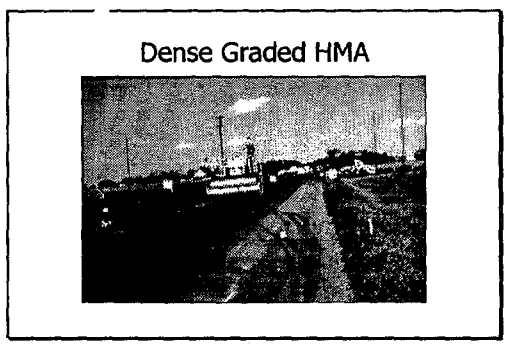
Slide 4




Slide 5




Slide 6

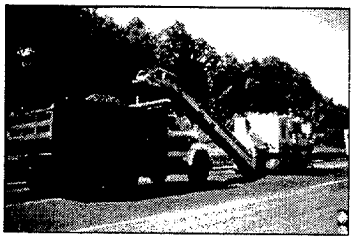


Slide 7

## Open Graded Friction Course

Slide 8

## Milling



Slide 9

### Rehabilitation Alternatives

| Problem | Rehabilitation Method | | |
|---|---|---|---|
| | Overlay | Recycling | Reconstruction |
| Cracking | X | X | X |
| Rutting | X | X | X |
| Raveling | X | | |

Slide 10

## Selection of Rehabilitation Alternative

- Engineering Consideration
- Economic Consideration
- Energy Consideration

Slide 11

## Engineering Considerations

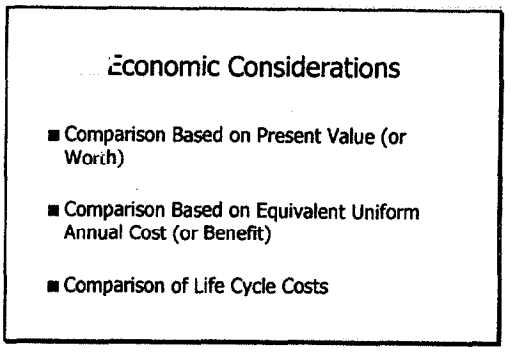
- Ride Quality of Existing Pavement
- Type, Extent and Severity of Distress
- Structural Capacity
- Drainage Conditions
- Design Life Required
- Material Used in Existing Pavement
- Age of Pavement

Slide 12

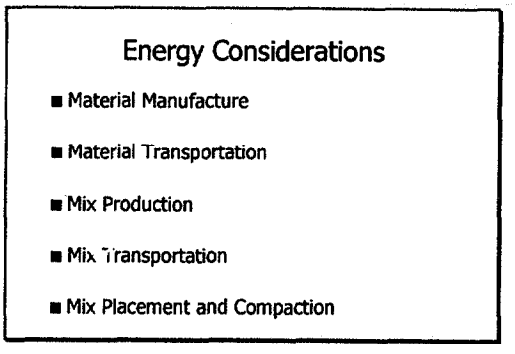
## Engineering Considerations (Continued)

- Type, Frequency and Cost of Past Maintenance
- Construction Considerations
  - Overhead Clearance
  - Curbs and Gutters
  - Drainage Structures
  - Shoulders, Median Barriers and Guardrails

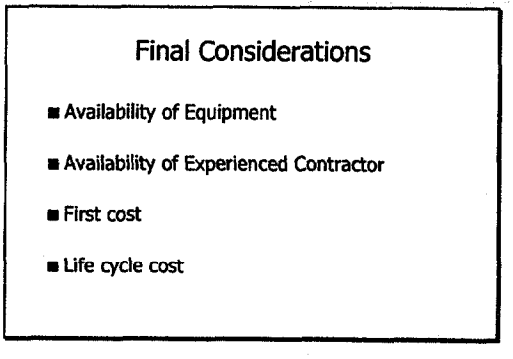
Slide 13




Slide 14




Slide 15



Slide 16

## Final Considerations

- Traffic control
- length of construction
- impact on adjacent business
- utility relocation and interference

Slide 17

## Selection of Recycling Method

- Hot Mix Recycling
- Hot In-Place Recycling
- Cold In-Place Recycling
- Full Depth Reclamation

Slide 18

## Hot Mix Recycling : Process

- RAP is Combined with New Aggregate and Asphalt Binder or Recycling Agent in a Hot Mix Plant
- Mix is Transported to Paving Site, Placed and Compacted

Slide 19

## Hot Mix Recycling: Advantages

- Significant Structural Improvement
- Performance as Good as Virgin Mix
- Most Surface Defects, Deformation, and Cracking Corrected

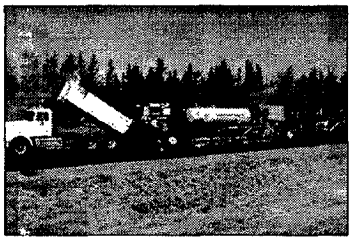
Slide 20

## Hot In-Place Recycling: Process

- Existing Asphalt Surface is Heated, Scarified to a Depth from 19 to 38 mm
- Scarified Material Combined with Aggregate and/or Asphalt Binder and/or Recycling Agent and Compacted
- New Overlay May or may Not be Provided

Slide 21

## Hot In-Place Recycling Process



Slide 22

## Hot In-Place Recycling: Advantages

- Surface Cracks Eliminated
- Ruts, Shoves, Bumps Corrected
- Aged Asphalt is Rejuvenated
- Aggregate Gradation and Asphalt Content Can be Modified
- Reduced Traffic Interruption During Construction
- Hauling Cost Minimized

Slide 23

## Cold In-Place Recycling : Process

- Existing Asphalt pavement Milled (75 to 100 mm Depth)
- RAP Sized if Needed, Mixed with Recycling Agent
- Placed and Compacted

Slide 24

## Cold In-Place Recycling Operation

Slide 25

## Cold In-Place Recycling : Advantages

- Significant Structural Improvements
- Most Pavement Distress Treated
- Ride Quality Improved
- Hauling Costs Minimized
- Minimal Air Quality Problems
- Pavement Widening Possible

Slide 26

## Full Depth Reclamation : Process

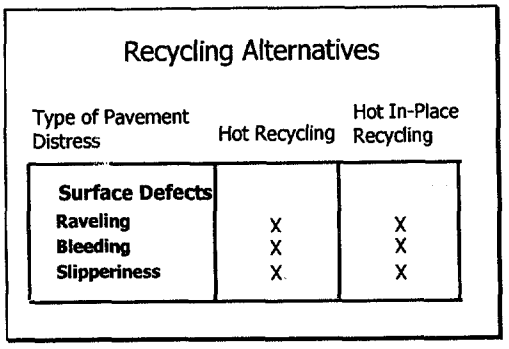
- All HMA Layers and Predetermined Thickness of Underlying layer Pulverized
- Stabilized with Additives
- Shaped and Compacted
- Surface Course is Applied

Slide 27

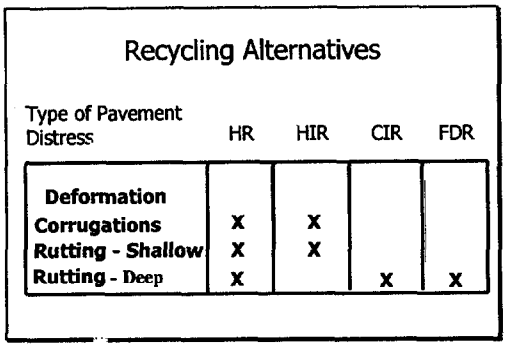
## FDR: Advantages

- Most Pavement Distress Treated
- Hauling Cost Minimized
- Significant Structural Improvements Especially in Base
- Eliminates Material Disposal Problems
- Improves Ride Quality

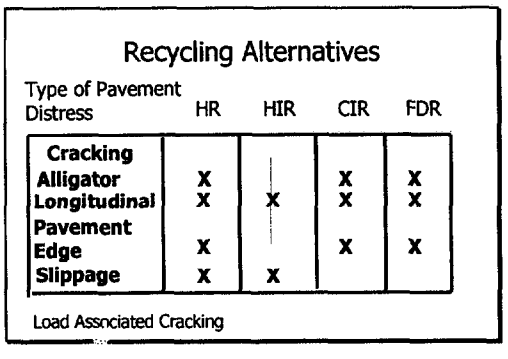
Slide 28




Slide 29




Slide 30



Slide 31

## Recycling Alternatives

| Type of Pavement Distress | HR | HIR | CIR | FDR |
|---|---|---|---|---|
| **Cracking** | | | | |
| **Block (Shrinkage)** | X | | X | X |
| **Longitudinal-joint** | X | X | | |
| **Transverse** | X | | X | X |
| **Reflection** | X | | X | X |

Non-Load Associated Cracking

Slide 32

## Distress

- Surface Defects
  - Raveling
  - Bleeding
  - Slipperiness or Polishing
- Deformation
  - Rutting
  - Corrugation or Washboarding

Slide 33

## Distress (Continued)

- Cracking (Load Associated)
  - Alligator
  - Pavement Edge
  - Slippage
- Cracking (Nonload Associated)
  - Transverse (Thermal)
  - Block
  - Longitudinal Joints

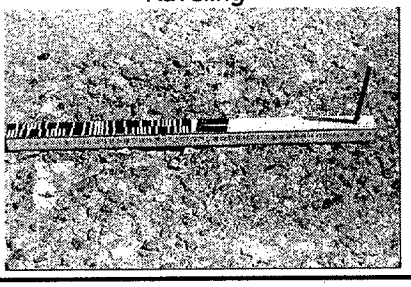
Slide 34

## Distress (Continued)

- Reflective Cracking
- Maintenance Patching

Slide 35

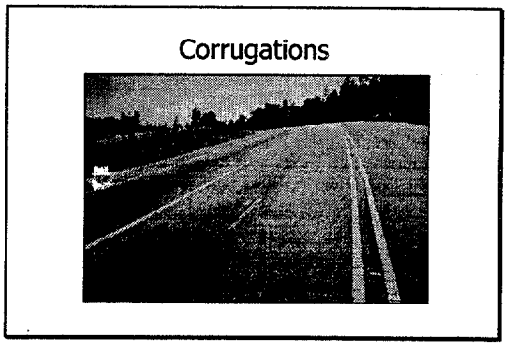
## Raveling



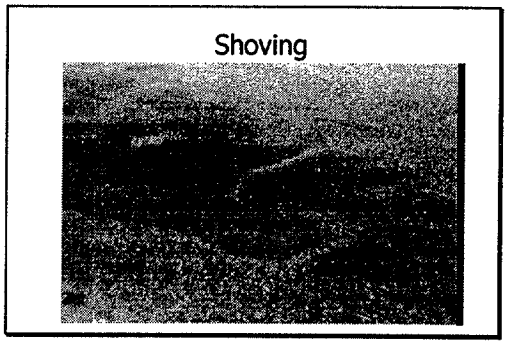
Slide 36

## Bleeding

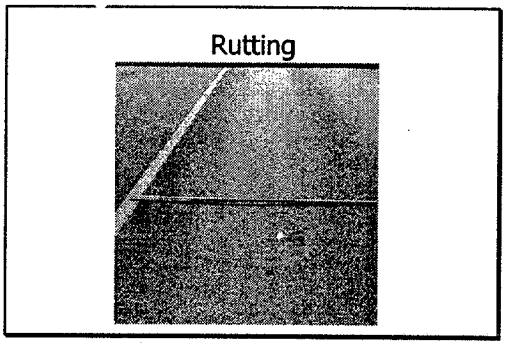
Slide 37



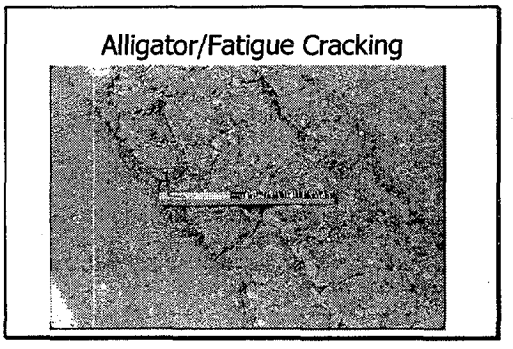

Slide 38



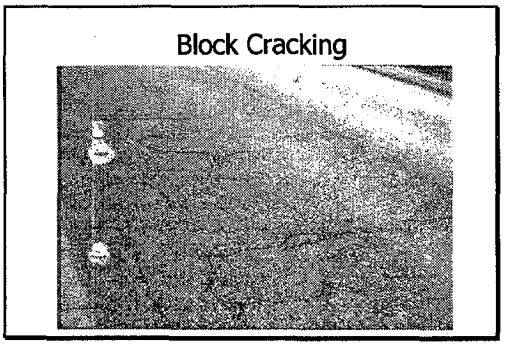

Slide 39



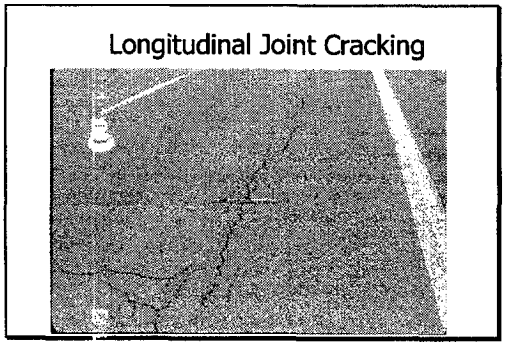
Slide 40



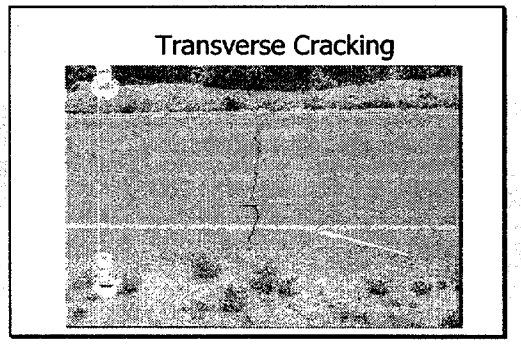

Slide 41



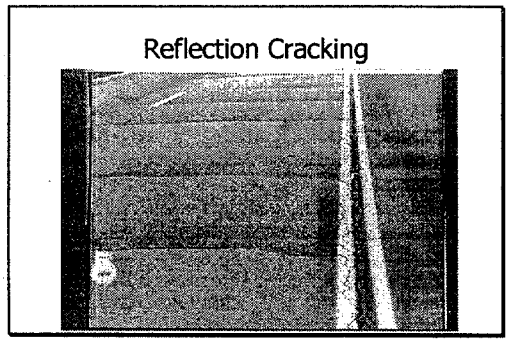

Slide 42



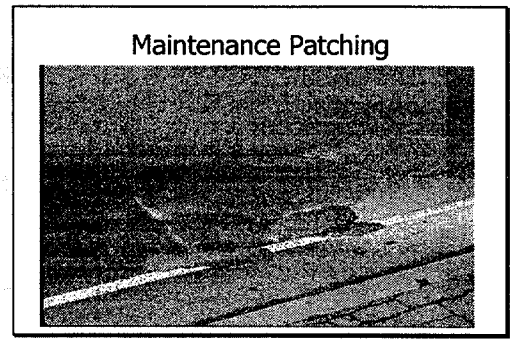
Slide 43




Slide 44




Slide 45



Slide 46

## Applicability and Considerations

| Process | Applicability | Considerations |
|---|---|---|
| Hot Mix Recycling | Can treat surface defects, deformations, cracks, and maintenance patching | Percentage of RAP depends on recycled mix properties and type of plant |

Slide 47

## Applicability and Considerations

| Process | Applicability | Considerations |
|---|---|---|
| Hot In-Place Recycling | Can treat surface defects, corrugation and surface rutting, longitudinal and slippage crack | Sufficient amount of work and space for maneuvering of equipment are required; crack sealing material can cause smoke |

Slide 48

## Applicability and Considerations

| Process | Applicability | Considerations |
|---|---|---|
| Cold In-Place Recycling | Can treat rutting in sub-surface layers, load associated cracks, maintenance patching | May require curing period, followed by application of wearing surface; bigger equipment train need sufficient maneuvering space. |

Slide 49

## Applicability and Considerations

| Process | Applicability | Considerations |
|---|---|---|
| Full Depth Reclamation | Can treat rutting in sub-surface layers; particularly suitable for roads with base problems or insufficient structural capacity | Requires wearing course; may require significant amount of curing time; lack of proper guidelines; experienced supervisor needed |

Slide 50

## Summary

Selection of Pavement for Recycling and Recycling Strategies

Slide 51

## Selection of Pavement for Recycling and Recycling Strategies

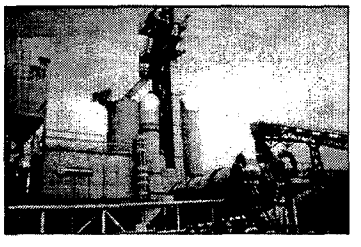
???

Slide 1

# Economics of Recycling

Slide 2

## Drum Mix Plant



Slide 3

## Estimated Savings from Using RAP Materials

| Item | Cost Per Ton ($) | Percent Used | Total Cost Per Ton ($) |
|---|---|---|---|
| Aggregate | 5.00 | 94 | 4.70 |
| Asphalt | 120.00 | 6 | 7.20 |
| Virgin Mix | | | 11.90 |
| RAP | | | |
| Trucking | 2.00 | | 2.00 |
| Milling | 1.70 | | 1.70 |
| RAP | | | 3.70 |
| Savings Per Ton of RAP Used | | | 8.20 |

Slide 4

## Savings by Using RAP

| Percent of RAP | Cost/Ton | Savings ($/Ton) | Savings (%) |
|---|---|---|---|
| 0 % | 11.90 | | |
| 20 % | 10.26 | 1.64 | 14 |
| 30 % | 9.44 | 2.46 | 21 |
| 40 % | 8.62 | 3.28 | 28 |
| 50 % | 7.80 | 4.10 | 34 |

Slide 5

Summary of Cost Savings- FHWA Survey (1984)

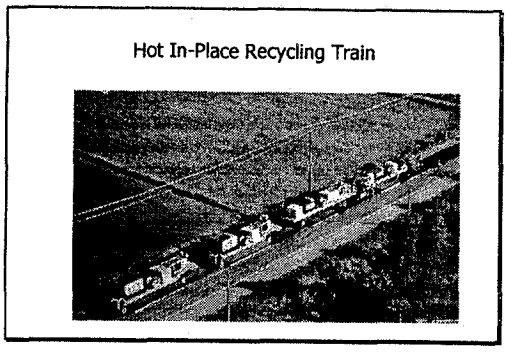
| Area | Total Tonnage (1000) 1984 | Average Savings Per Ton ($) | Average % Savings versus 100% New Material ($) | Total Savings ($1000) |
|---|---|---|---|---|
| North-East | 500 | 2.80 | 10 | 1400 |
| South-East | 4,000 | 5.67 | 20 | 22,300 |
| North-Central | 12,000 | 5.26 | 18 | 62,600 |
| South-Central | 2,000 | 5.32 | 20 | 10,000 |
| Western | 1,600 | 5.12 | 21 | 8,200 |
| Total | 20,000 | --- | --- | 104,500 |
| Average | --- | 4.83 | 18 | --- |

Slide 6

## Typical Cost Savings : Hot Mix Recycling

| Agency | Year (s) | % Average Savings |
|---|---|---|
| Florida DOT | 1981-1983 | 24-26 |
| Saskatchwan | 1985 | 20-30 |
| U.S. Corps of Engineers | 1986 | 16 |
| Wisconsin DOT | 1980-1985 | 39-49 |

Slide 7

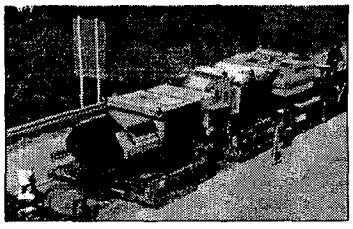



Slide 8


Slide 9

Slide 10

## Hot In-Place Recycling (Remixing)



Slide 11

## Typical Costs of Hot In-Place Recycling (Table)

| Method | Cost ($/sq.m) |
|---|---|
| A. Heater Scarification | 1.2 |
| B. Repaving 25 mm Recycling + 25 mm HMA Overlay | 3.5 |
| C. Remixing 25 mm Recycling + 20 % New Aggregate | 2.8-3.7 (50 mm depth) |

Slide 12

## Savings with HIR

| Agency | HIR Process | Savings over Control (%) |
|---|---|---|
| Florida DOT | Repaving | 25 |
| FAA Texarkana, Texas | Repaving | 50 |

Slide 13

## Savings with HIR

| Agency | HIR Process | Savings over Control (%) |
|---|---|---|
| Mississippi SHD | Remixing | 40 |
| Oregon DOT | Remixing | 17 |
| Texas DOT | Remixing | 34 |

Slide 14

Cold In-Place Recycling Train

Slide 15

## Typical Costs of Cold In-Place Recycling

| Method | Cost ($/sq.m) |
|---|---|
| Oregon DOT (1989-1990) | |
| 5 cm Cold Recycling with Chip Seal | 2.51 |
| 5 cm Cold Recycling without Chip Seal | 1.80 |

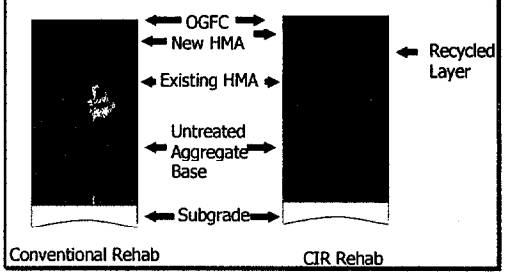
Slide 16

## Percent Cost Savings

| State | % Cost Savings |
|---|---|
| California | 21- 37 |
| Iowa | 67 |
| Kansas | 53 |
| Missouri | 50 |
| Montana | 21 |
| Oregon | 24 |
| Pennsylvania | 16 |
| Vermont | 28-31 |

Slide 17

## Typical Sections in New Mexico




Slide 18

## Initial Construction Cost in New Mexico

| Savings | Maximum | Minimum | Average |
|---|---|---|---|
| $/lane-km | 14,296 | 1,593 | 7074 |
| $/square m | 2.81 | 0.53 | 1.90 |

Slide 19

## Life Cycle Cost in New Mexico

| Rehab Option | Initial Cost ($) | Maintenance Cost ($) | Total Cost ($/m$^2$) |
|---|---|---|---|
| Mill and Overlay (Total) | 8.78 | 0.314 | 9.09 |
| CIR (Total) | 6.88 | 0.159 | 7.04 |
| Cost Savings with CIR | 1.90 | 0.155 | 2.05 |

Slide 20

## Savings with CIR

- Maintenance of Cracked Pavements

  After 4 Years for Mill and Overlay Projects

  After 8 Years for CIR Projects

Slide 21

## FDR Train

Slide 22

## Savings in FDR

| Option | Cost |
|---|---|
| Full Reconstruction: Excavate, place grade and compact, and pave | $\$16.12/m^2$ |
| FDR and pave | $\$7.25/m^2$ |

Slide 23

## Savings with Recycling

- Savings is also Achieved by

  Not Transporting RAP

  And

  Not Using Landfill Space

Slide 24

## Recycling

- Recycling Reuses Non-Renewable Resources
- Should be Used Even if Cost is Equal to Conventional Rehabilitation Options
- Better Option in Many Cases

Slide 25

Better Option When Overlay is Limited to Maintain Underpass

Slide 26

## Summary

Economics of Recycling

Slide 27

Economics of Recycling

???

Slide 1

# Hot Mix Asphalt Recycling: Batch Plant (Construction Methods and Equipment)

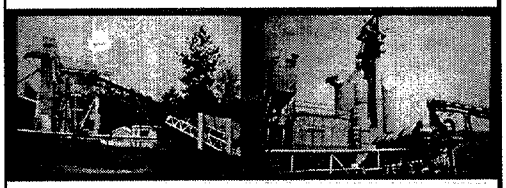
Slide 2

## Hot Mix Asphalt Recycling

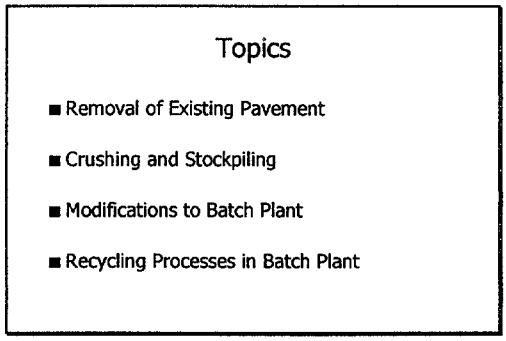
- **Batch Plant**
- Drum Plant

Slide 3

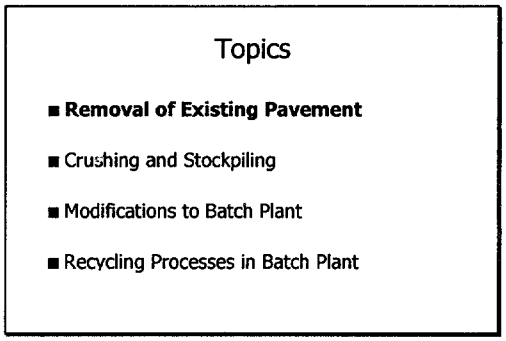
Batch Plant | Drum Plant



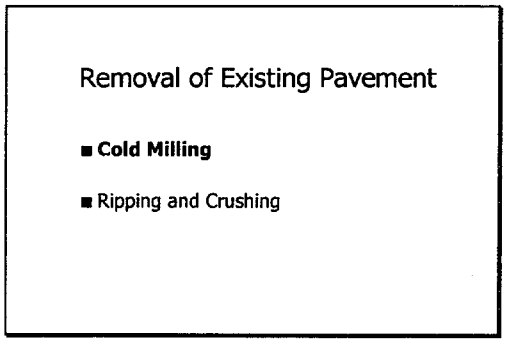
Slide 4




Slide 5




Slide 6



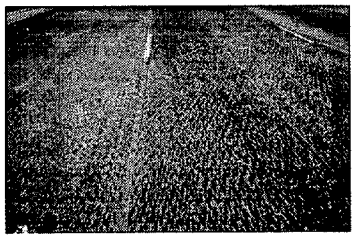
Slide 7

## Cold Milling

- Significant Development for Recycling
- Most Widely Used
- Removes HMA Surface to Specified Depth
- Provides Uniform Profile and Cross Slope

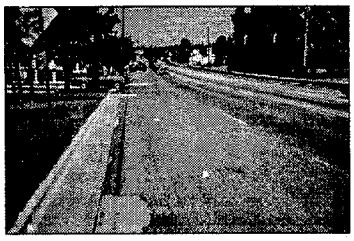
Slide 8

Typical Surface Resulting from Cold Milling



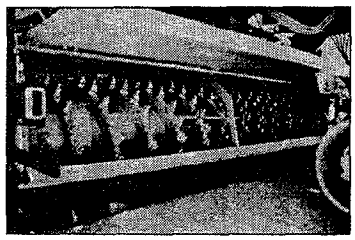
Slide 9

Curb Reveal



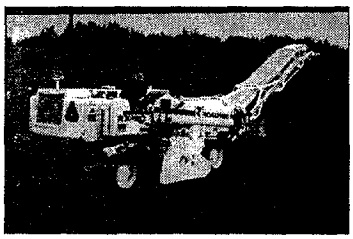
Slide 10

Teeth on Drum of Cold Milling Machine



Slide 11

Small Cold Milling Machine



Slide 12

Full Lane Cold Milling Machine

Slide 13

Full Lane Cold Milling Machine

Slide 14

Full Lane Cold Milling Machine

Slide 15

Removal of Existing Pavement

- Cold Milling
- **Ripping and Crushing**

Slide 16

## Ripping and Crushing

- Existing Roadway to be Upgraded for Heavy Traffic
- Existing Roadway of Uniform Material

Slide 17

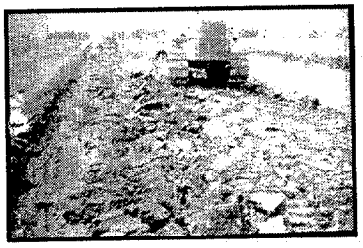
## Pavement Ripping with Dozer

Slide 18

## Dozer with Rear Mounted Ripper Tooth

Slide 19

## Ripping and Crushing



Slide 20

## Topics

- Removal of Existing Pavement
- **Crushing and Stockpiling**
- Modifications to Batch Plant
- Recycling Processes in Batch Plant

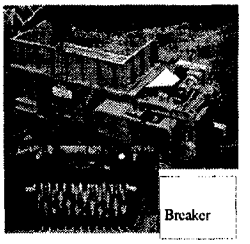
Slide 21

## Objective

- Reduce RAP to Maximum Acceptable Size
- Example: 95 % Passing 50 mm

Slide 22

RAP Breaker



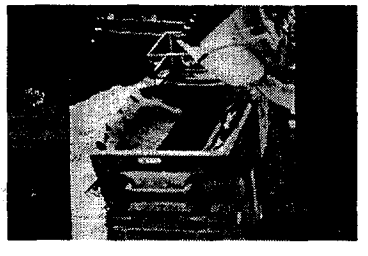

Slide 23

Types of Crushers

- Compression Crusher
- Impact Crusher

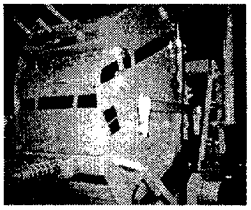
Slide 24

Primary Jaw Crusher



Slide 25

Horizontal Impact Crusher

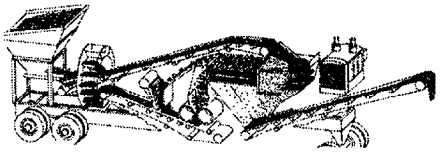


Slide 26

Hammermill Impact Crusher

Slide 27

Jaw/Roll Crusher



Slide 28

Typical Use of Jaw/Roll Crusher

Double deck screen used for two products:

Fine (< 12.5 mm)

Coarse (12.5 - 19.5 mm)

Slide 29

## Pancaking

- Formation of dense mass of RAP
- Especially in Warm, humid days
- Problem in Jaw/Roll Crushers

Slide 30

## Steps in Crushing RAP

- Blend RAP thoroughly
- Crush RAP to One Smaller than Top Size in HMA

Slide 31

## Crushing of RAP

- Crush Material in Small Quantity
  - Easier to Sample
  - Easier to Identify Material
  - Can be Used Quickly

Slide 32

## Stockpiling

- Separate Based on Sources/Mix Types
- Avoid Consolidation
  - No Loaders, Dozers or Trucks on Stockpile
- Protect from Moisture Intrusion
- Protect from Contamination

Slide 33

## Radial Stacker for Stockpiling RAP

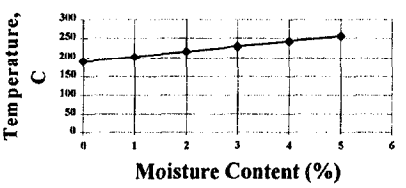
Slide 34

## RAP Piles

- Use Conical RAP Piles
- Crust Helps to Shed water
- Crust is Easily Broken by Frontend Loader
- Prevents Compaction

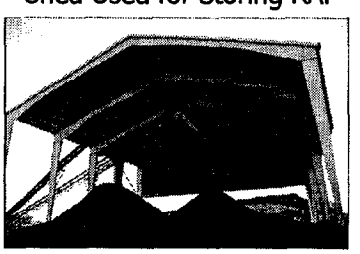
Slide 35

## Moisture Content versus Drying temperature




Slide 36

## Shed Used for Storing RAP



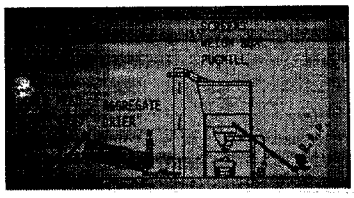
Slide 37

## Topics

- Removal of Existing Pavement
- Crushing and Stockpiling
- **Modifications to Batch Plant**
- Recycling Processes in Batch Plant

Slide 38

## Schematic of Maplewood Method



Slide 39

## Superheating Aggregates

- Aggregate Dryer
  - Adequate Veil
  - Cooling Period to Avoid Warping
- Dryer Exhaust System
  - Lower Temperature to Prevent Damage to Baghouse

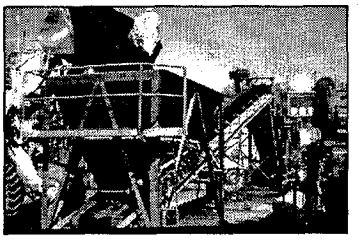
Slide 40

## RAP Feeder and Conveying System

- RAP Cold Feed Bin
  - Steep Sides, Large Discharge Opening
- RAP Conveying System
  - Heavy Duty Motor to Ensure Frequent Starting and Stopping

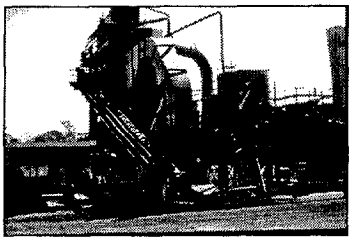
Slide 41

## Photograph of RAP Cold Feed Bin



Slide 42

## Photograph of RAP Conveying System



Slide 43

## Moisture and Dust Emissions

- Adequate Venting for Weigh Hopper and Pugmill
- Moisture Emission Depends on Moisture Content of RAP Material

Slide 44

## Storage Silos

- Allow Heat Transfer and Attain Temperature Equilibrium

Slide 45

## Topics

- Removal of Existing Pavement
- Crushing and Stockpiling
- Modifications to Batch Plant
- **Recycling Processes in Batch Plant**

Slide 46

## Recycling Processes

- Method 1
  - RAP Fed into Boot of Hot Elevator
- Method 2
  - RAP Fed into Boot of Hot Elevator, Bypasses Screen, Goes into Fifth Hot Bin
- Method 3
  - RAP Fed into Weigh Hopper

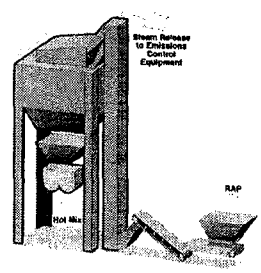
Slide 47

## Recycling Processes

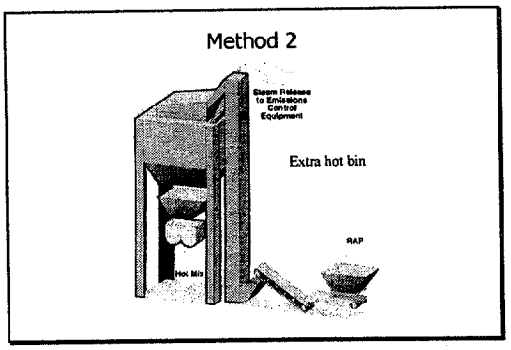
- Method 4
  - RAP Fed into a Bin which Discharges Directly into the Pugmill
- Method 5
  - Preheating RAP in Separate Dryer

Slide 48

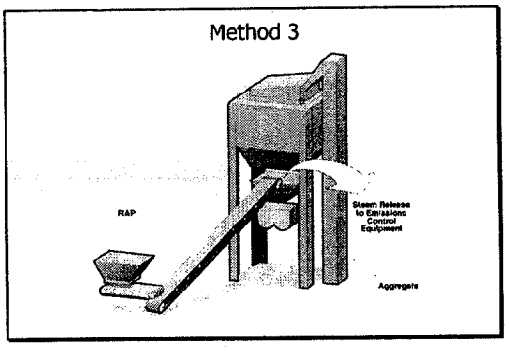
## Method 1



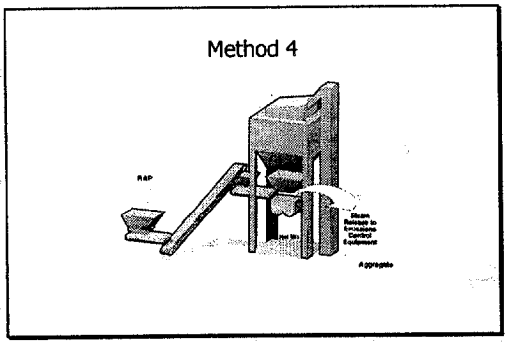
Slide 49




Slide 50

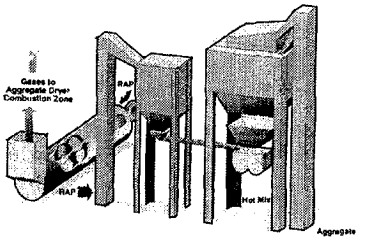



Slide 51



Slide 52

## Method 5



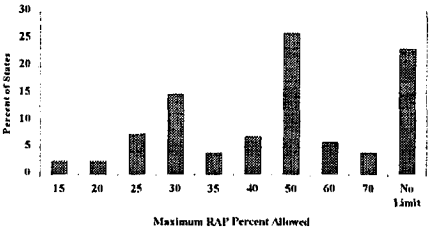

Slide 53

## Amount of RAP

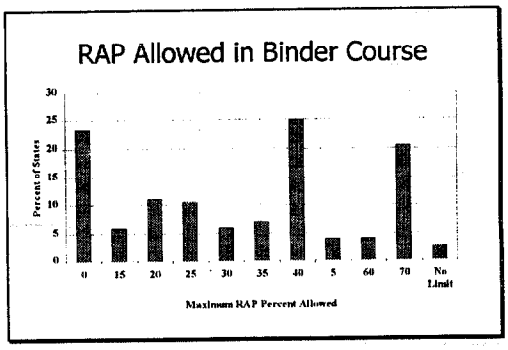
- Factors
  - Moisture Content of RAP
  - Temperature of Superheated Aggregate
  - Temperature of RAP
  - Temperature of Recycled Mix
  - Percent passing 0.075 mm Sieve
- Amount of RAP
  - Maximum :About 50 %
  - Practical : About 30 %

Slide 54

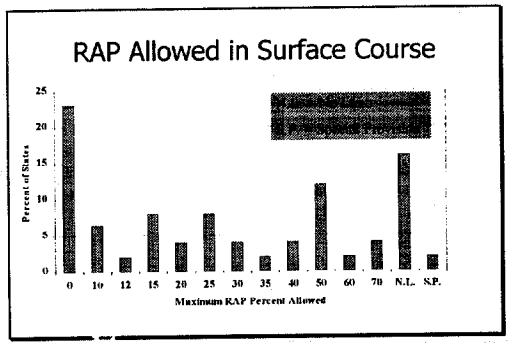
## RAP Allowed in Base Course



Slide 55




Slide 56




Slide 57

## Summary

Hot Mix Asphalt Recycling: Batch Plant (Construction Methods and Equipment)

Slide 58

Hot Mix Asphalt Recycling: Batch Plant (Construction Methods and Equipment)

???

Slide 1

# Hot Mix Asphalt Recycling: Drum Plant (Construction Methods and Equipment)

Slide 2

## Hot Mix Asphalt Recycling

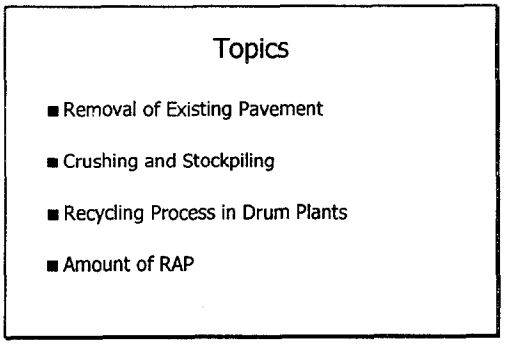
- Batch Plant
- Drum Plant

Slide 3

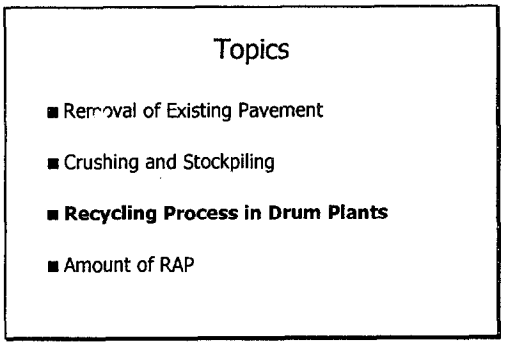
## Advantages of Recycling in Drum

- Portability
- High Percentage of RAP
- High Production Rates
- More Homogeneous Mix

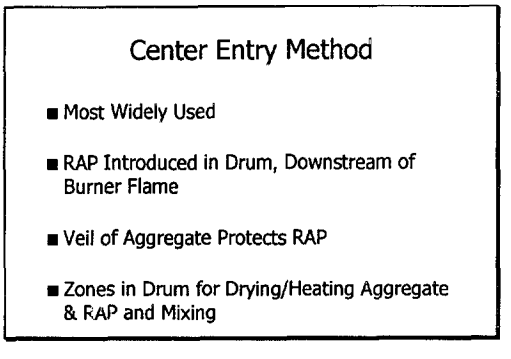
Slide 4



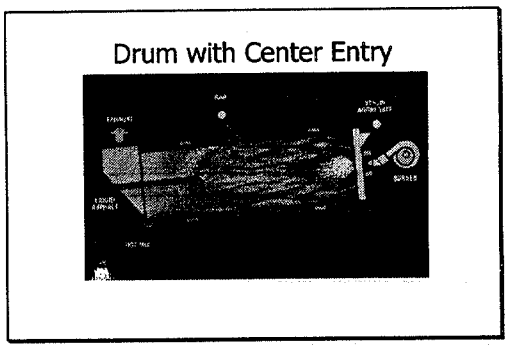

Slide 5



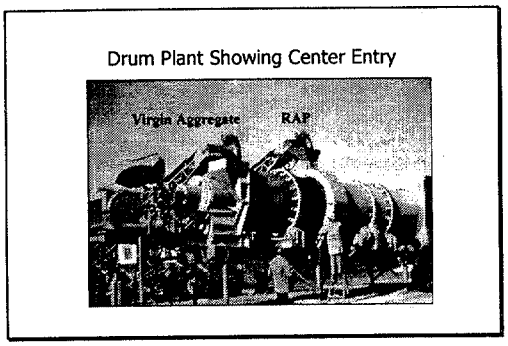

Slide 6



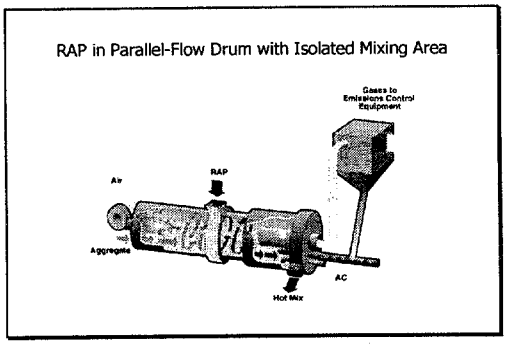
Slide 7



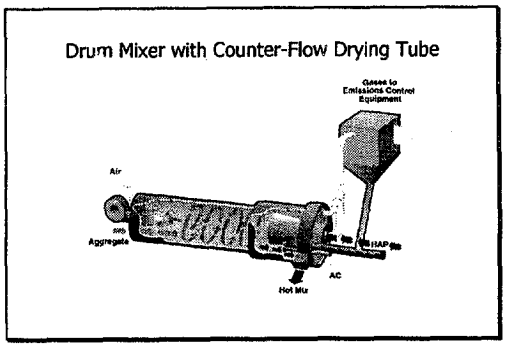

Slide 8



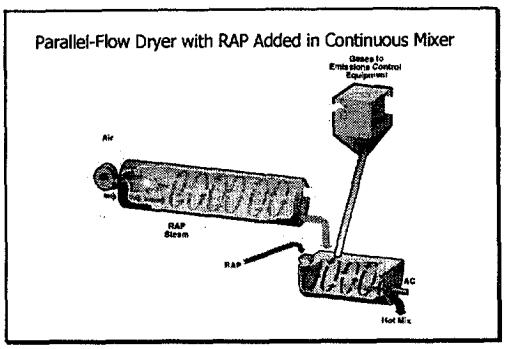

Slide 9



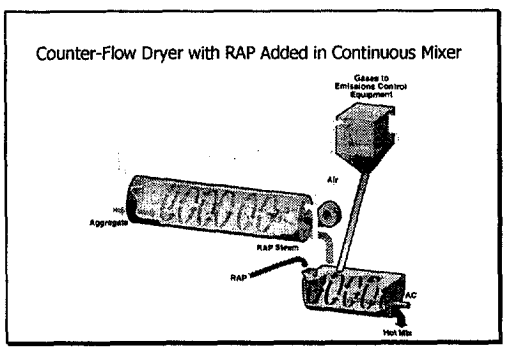
Slide 10



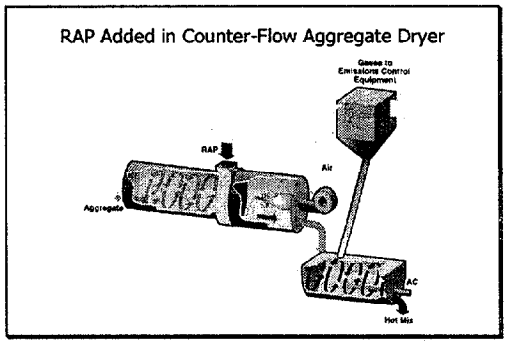

Slide 11



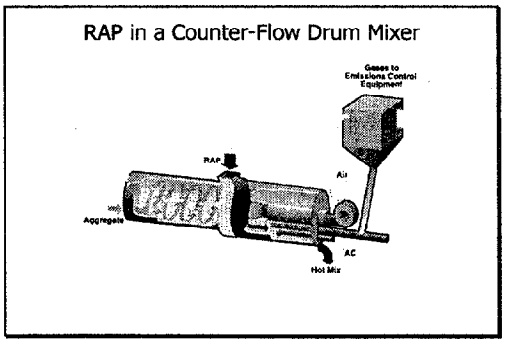

Slide 12



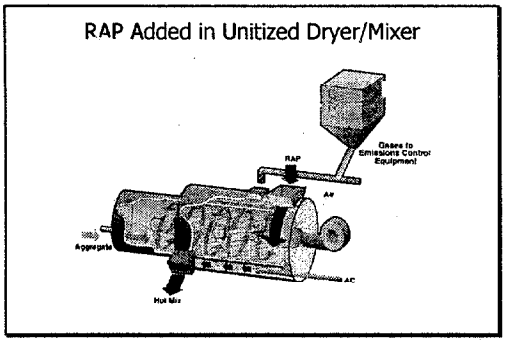
Slide 13




Slide 14




Slide 15



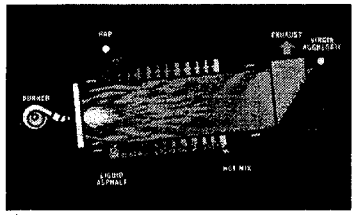
Slide 16

## Double Barrel

- Double Barrel, Counterflow Drum
- Aggregate Superheated in Inner Drum
- Meets RAP in the Annular Space
- Addition of Binder and Mixing in the Annular Space
- Shell of Inner Drum Used as Shaft of Coater
- Outer Shell Does Not Rotate

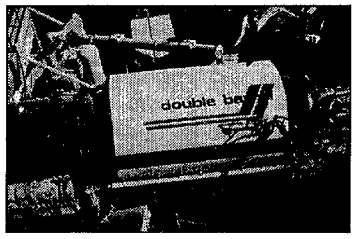
Slide 17

Schematic of Double Barrel Mixer



Slide 18

Double Barrel Drum



Slide 19

## Advantages of Double Barrel

- RAP and Asphalt Binder Not Exposed to Hot Gases
- Very Heat Efficient/Low Fuel Consumption
- Very Low Emissions
- Longer Life of Bags in Baghouse

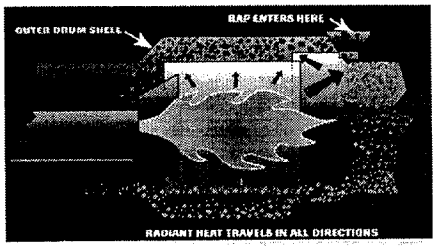
Slide 20

## Triple Drum

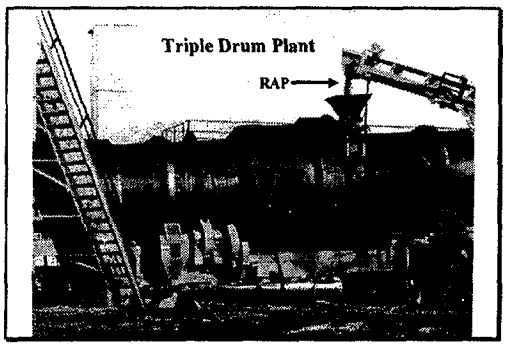
- Uses Stainless Steel Cylinder to Enclose Combustion Chamber
- Counterflow Drum
- RAP Material Introduced in Annular Space Formed by Outer Shell
- Superheated Virgin Aggregates Meet RAP in Annular Space

Slide 21

## Schematic of a Triple Drum Plant



Slide 22




Slide 23

## Advantage of Triple Drum

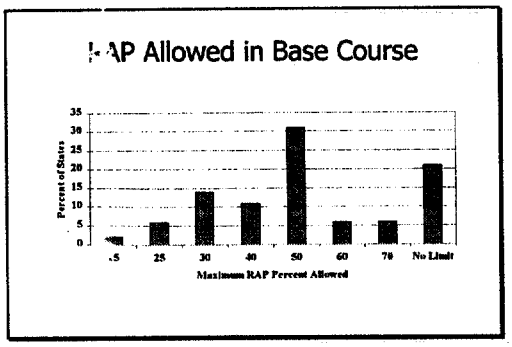
- The Stainless Steel Cylinder is Effective in Transferring Heat to the RAP Material through Conduction and Radiation

Slide 24

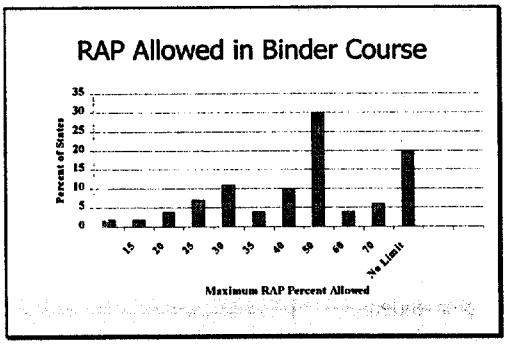
## Amount of RAP in Drum Plant Recycling

- Factors
  - Moisture Content of RAP
  - Temperature of Superheated Aggregate
  - Temperature of RAP
  - Temperature of Recycled Mix
- Amount of RAP
  - Maximum: About 70 %
  - Practical: About 30 % - 50 %

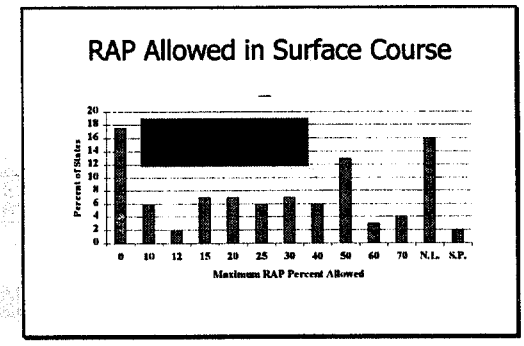
Slide 25




Slide 26




Slide 27



Slide 28

## Feeder Systems

- Bin
  - Low Capacity
  - Steep Sides
  - Long and Wide Bottom
- Material should be Dribbled

Slide 29

## Feeder Systems

- RAP
  - Do Not Leave in Bin for >2 Hours
- Feeders
  - Wide and with Sufficient Horsepower
- Vibratory Feeders Not Recommended

Slide 30

## Summary

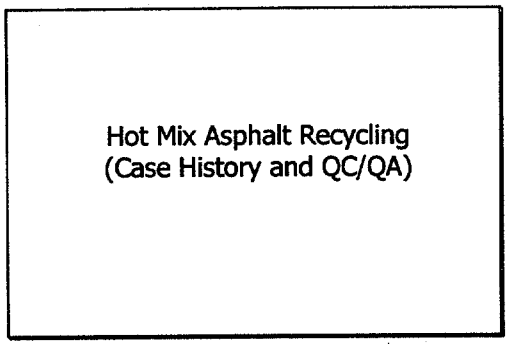
Hot Mix Asphalt Recycling: Drum Plant (Construction Methods and Equipment)

Slide 31

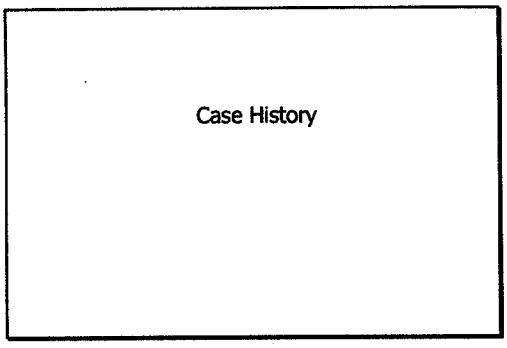
Hot Mix Asphalt Recycling: Drum Plant (Construction Methods and Equipment)

???

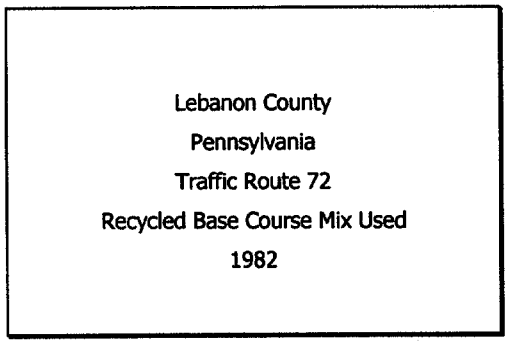
Slide 1




Slide 2




Slide 3



Slide 4

## Lebanon County

- Traffic

  ADT: 5000

  Truck Traffic: 20 %

Slide 5

RAP Stockpile

Slide 6

## Analysis of RAP

- Mix Composition (N = 10)
  - Asphalt Content 5.7%
  - Gradation
- Abson Recovery (N = 3)
  - Viscosity (60°C)
- 20% RAP to be Used in Batch Plant

Slide 7

## Gradation of Aggregate

| Sieve | RAP 20.0 % | 2B 63.3% | FA 16.7 % | Total Blend | Spec. |
|---|---|---|---|---|---|
| 38 mm | 100 | 100 | 100 | 100 | 100 |
| 12.5 mm | 100 | 50 | 100 | 68 | 40-75 |
| 4.75 mm | 84 | 4 | 100 | 36 | 20-47 |
| 2.36 mm | 65 | 2 | 76 | 27 | 15-37 |
| 0.075 mm | 18 | 0.3 | 6.5 | 4.9 | 2-6 |

Slide 8

## Calculation of % New Asphalt in the Total Asphalt

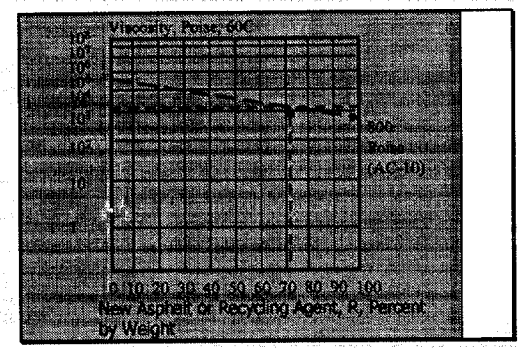
$$P_{nb} = \frac{(100^2 - rP_{sb})Pb}{100(100 - P_{sb})} - \frac{(100 - r)\,P_{sb}}{100 - P_{sb}}$$

$$= \frac{(100^2 - 80 \times 5.7)4}{100(100 - 5.7)} - \frac{(100 - 0)5.7}{100 - 5.7}$$

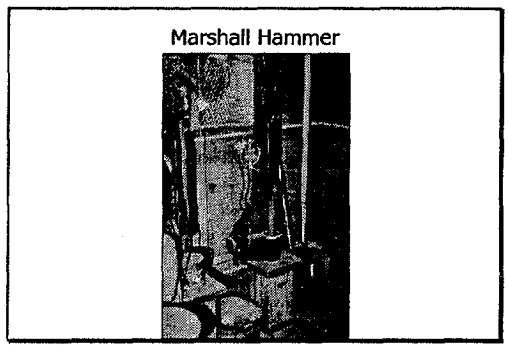
$$= 2.8$$

$P_{nb}$ = Percent of New Asphalt Binder in Recycled Mix
r = New Aggregate, Percent of Total Aggregate
$P_b$ = Estimated Asphalt Content of Recycled Mix
$P_{sb}$ = Asphalt Content of RAP Material

Slide 9

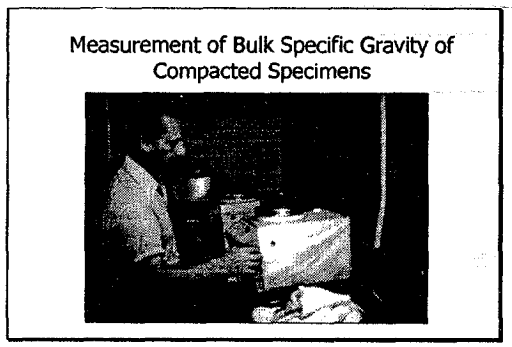


Slide 10



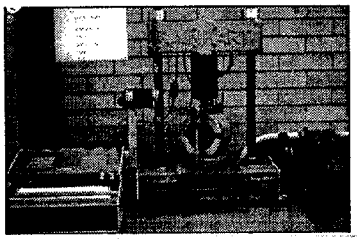

Slide 11


Slide 12



Slide 13

Marshall Stability Machine



Slide 14

Recycled Base Course
Mix Composition

| | |
|---|---|
| ■ RAP | 20.0% |
| ■ AASHTO 57 | 63.3% |
| ■ Fine Aggregate | 16.7 % |
| | 100.0 % |

■ Asphalt Content: 4.0 %

Slide 15

RAP Being Fed Into RAP Bin

Slide 16

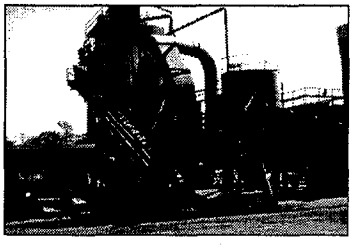
RAP Being Fed Into RAP Bin
(Another View)

Slide 17

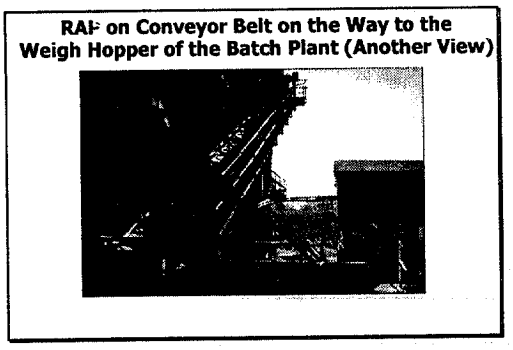
**Grizzly Screen Used**

Slide 18

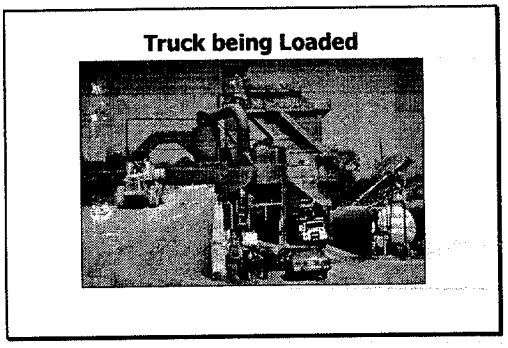
**RAP on Conveyor Belt on the Way to the Weigh Hopper of the Batch Plant**



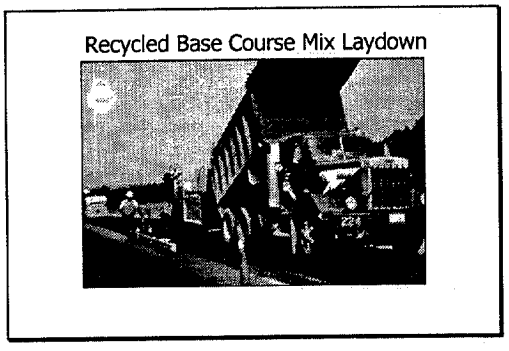
Slide 19




Slide 20




Slide 21

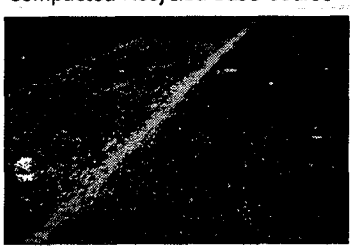


Slide 22

Compaction in Progress

Slide 23

Compacted Recycled Base Course



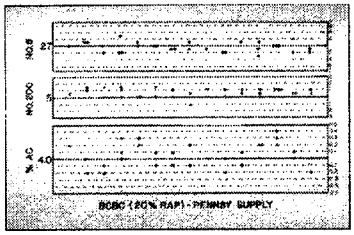
Slide 24

## Test Data

| N = 31 | 2.36 mm | 0.075 mm | % AC | % Voids |
|---|---|---|---|---|
| Design | 27.0 | 4.9 | 4.0 | 5.5 |
| Mean | 26.5 | 5.6 | 4.0 | 4.5 |
| Std. Deviation | 1.3 | 0.6 | 0.17 | 0.5 |
| 95 % C.L. (±) | 2.6 | 1.2 | 0.34 | 1.0 |

Slide 25

Control Charts



Slide 26

Finished HMA

Slide 27

## Performance

- Distress Survey after 10 Years Indicated No Significant Difference Between Control and Recycle Section in terms of
  - Rutting
  - and
  - Cracking

Slide 28

Quality Control (QC) and
Quality Assurance (QA)

Slide 29

## QC/QA

- Similar to Conventional HMA Mixes
- Additional Testing for Recycled Mixes
  - Composition of RAP (Asphalt Content and Gradation)
  - Consistency of Binder Recovered From Recycled Mix

Slide 30

## Aggregate Gradation

- Aggregate Stockpile
- RAP Stockpile
- Cold Feeder Belt
- Hot Bins (Batch Plant)
- Aggregate Recovered by Extraction or Ignition of Recycled Mix

Slide 31

Asphalt Content

- Solvent Extraction
- Nuclear Asphalt Content Gauge
- NCAT Ignition Method

Slide 32

Testing Recovered Asphalt Binder

- Test Recovered Asphalt Binder
  - → Viscosity (60°C)
  - → G*/Sin delta

Slide 33

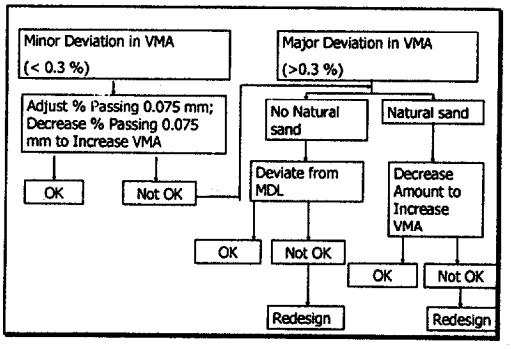
Field Management of
Volumetric Properties

Slide 34

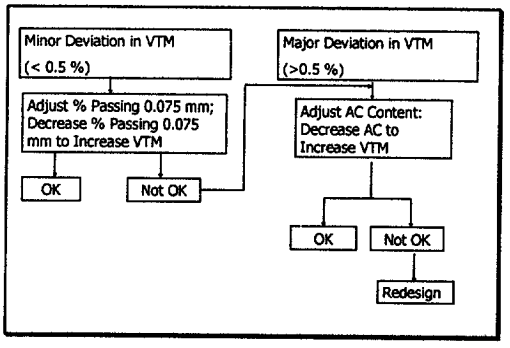
## Volumetrics Properties

- VMA
  - No. 2.36 (Amount of FA)
  - 0.3mm and 0.6 mm (Amount of Natural Sand)
- VTM
  - Asphalt Content
  - % Passing 0.075 mm
  - 2.36 mm through 0.15 mm

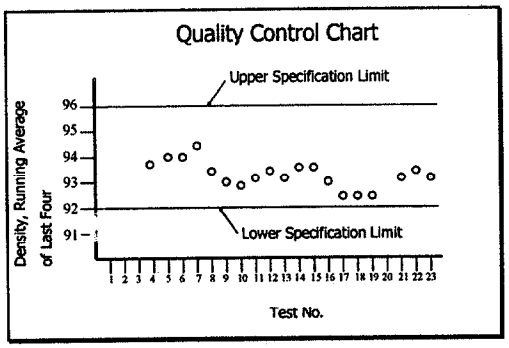
Slide 35




Slide 36



Slide 37




Slide 38

Hot Mix Asphalt Recycling

(Case History and QC/QA)

???

Slide 1

# Hot In-Place Recycling (HIR) Construction Methods & Equipment

Slide 2

## Description

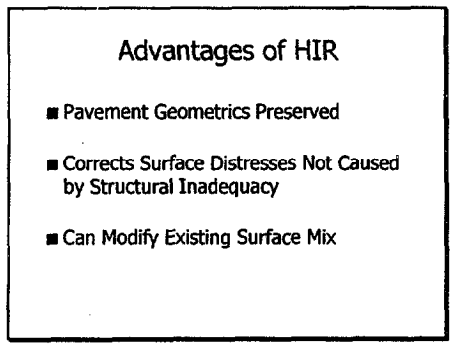
- On site, Hot In-Place Method That Rehabilitates Deteriorated Asphalt Pavements and Thereby Minimizes Use of New Materials
- Depth Recycled: 20-50 mm (25 mm Most Common)

Slide 3

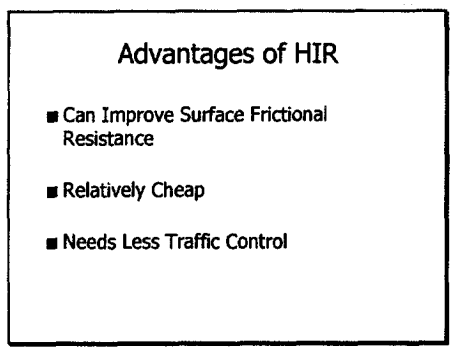
## 4 Basic Steps

- Softening Pavement with Heat
- Scarification or Mechanical Removal of Softened Material
- Mixing with Recycling Agent, New Aggregate, New Binder, or New Mix
- Laydown and Paving

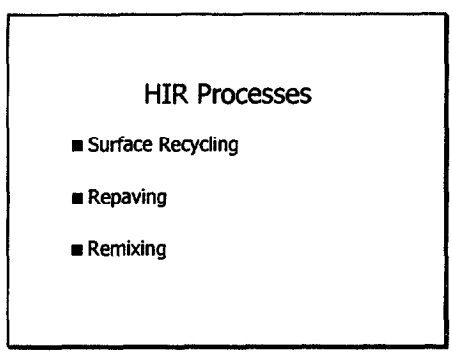
Slide 4




Slide 5




Slide 6



Slide 7

## HIR Processes

- **Surface Recycling**
- Repaving
- Remixing

Slide 8

## Surface Recycling

- Rehabilitation Process That Restores Cracked, Brittle, and Irregular Pavement in Preparation for a Final Thin Wearing Course
- Depth of 20-25 mm Most Common (50 mm Possible)

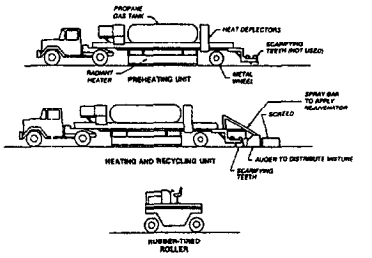
Slide 9

## Surface Recycling

- Single-Pass Method
- Two-Pass Method (HMA Overlay Placed as a Separate Operation After surface recycling)

Slide 10

## Schematic of Surface Recycling

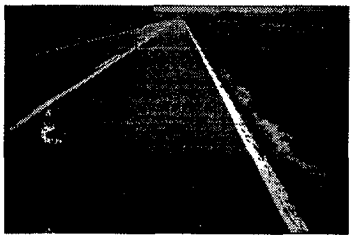



Slide 11

## Surface Recycling Equipment

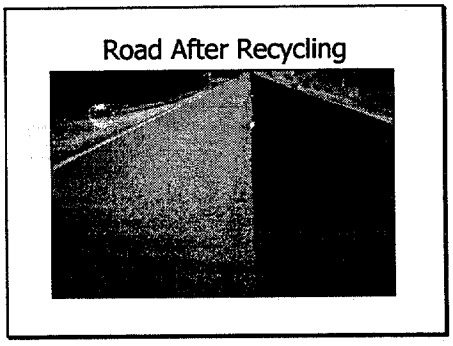
Slide 12

## Road Before Recycling



Slide 13


Slide 14




Slide 15

Slide 16

## Recycling in Residential Area

Slide 17

## Surface Recycling

- Radiant or Infrared Heating
- Propane - Most Common Fuel
- Spring Loaded Scarifiers
- Effectiveness of Adding Recycling Agent without Mixing

Slide 18

## HIR Processes

- Surface Recycling
- **Repaving**
- Remixing

Slide 19

## Repaving

- Definition: Surface Recycling Method Combined with Simultaneous Overlay of New HMA to Form a Thermal Bond Between Recycled and New Layers
- Depth: 25 to 50 mm

Slide 20

## Steps in Repaving Process

- Multiple Heating Units to Soften Asphalt Surface
- Scarify Softened Pavement
- Add and Mix Recycling Agent with RAP

Slide 21

## Steps in Repaving Process

- Spread the Recycled Mix with Screed
- Spread the New Mix with Screed on Top of the Recycled Mix
- Compact both Layers of Recycled and New Mixes

Slide 22

## Advantages

- Elimination of Minor Rutting, Shrinkage, Cracking, and Raveling
- Very Thin Overlay (12 mm) Can be Used to Yield Economical, Skid-Resistant, and Virgin HMA Surface

Slide 23

## Repaving Process

- Multiple - Pass
- Single - Pass

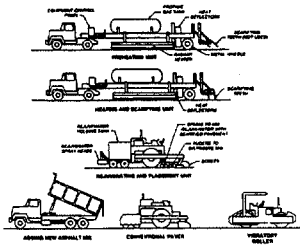
Slide 24

## Repaving Process

- **Multiple - Pass**
- Single - Pass

Slide 25

Schematic of Multiple-Pass Repaving



Slide 26

Multiple - Pass Repaving

Slide 27

Repaving Process

- Multiple - Pass
- **Single - Pass**

Slide 28

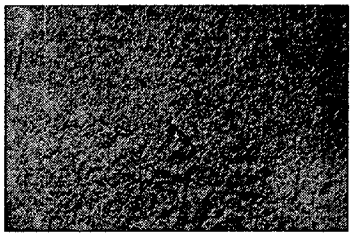
Schematic of Single - Pass Method

Slide 29

Single-Pass Recycling

Slide 30

Pavement Before Repaving

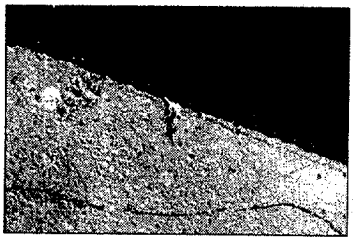


Slide 31

Single - Pass Repaving

Slide 32

Pavement After Repaving



Slide 33

HIR Processes

- Surface Recycling
- Repaving
- **Remixing**

Slide 34

## Remixing Process

- Heating Asphalt Pavement 37.5-50 mm
- Scarification and Collection of RAP in Windrow
- Add Virgin Aggregate, Recycling Agent, or Virgin HMA Mix
- Mix in a Pugmill
- Spread Recycled Mix and Compact

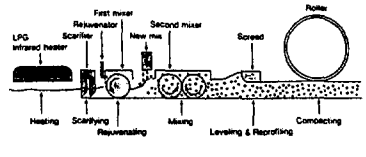
Slide 35

## Advantages

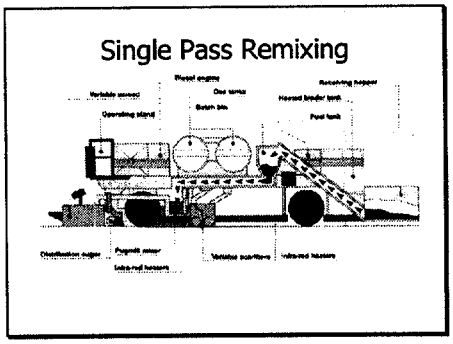
- Elimination of Rutting, Cracking, and Oxidation in Top 50 mm of Asphalt Pavement
- Restoration of Existing Asphalt Mix to Desired Mix Composition and Strength by Adding New Aggregate, Binder, or New Mix

Slide 36

## Schematic of Remixing Method

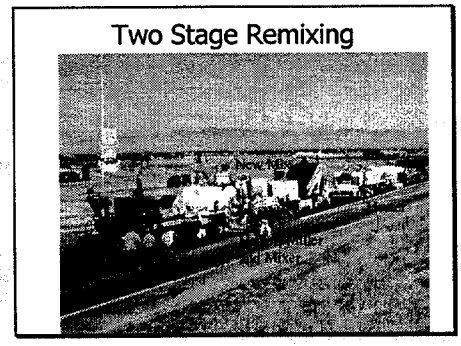


Slide 37



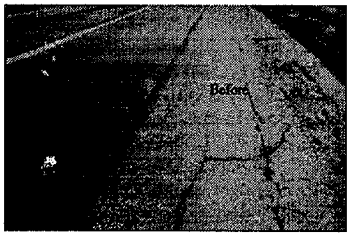

Slide 38


Slide 39



Slide 40

Road Before and After Recycling




Slide 41

Recycling in Local Roads

Slide 42

Problem with Crack Filling Material

Slide 43

## Problem with Crack Filling Material

- Flare-ups Can Occur Under Preheaters
- Can Use Strip of Sand or Hydrated Lime
- If Present in Excessive Amount, Material Must Be Removed

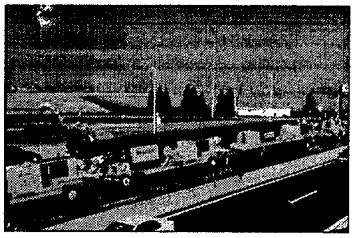
Slide 44

## New Development

- Use of High Intensity Infrared Heaters
  - Overheat and Damage Asphalt
  - May Cause Emission
- New Equipment use Hot Air/Low Level Infrared heat

Slide 45

## Equipment with Hot Air/Infrared Heater



Slide 46

## Summary

Hot In-Place Recycling (HIR) Construction Methods & Equipment

Slide 47

Hot In-Place Recycling (HIR) Construction Methods & Equipment

???

Slide 1

Hot In-Place Recycling (HIR)
Case Histories and QC/QA

Slide 2

HIR

- Existing Pavement Heated
- Scarified
- Mixed with Virgin Aggregate and/or Recycling Agent and/or Virgin HMA
- Laid and Compacted

Slide 3

Types of HIR

- Surface Recycling
- Repaving
- Remixing

Slide 4

Repaving Process
Orange County, Florida
Case History

Slide 5

Orange County

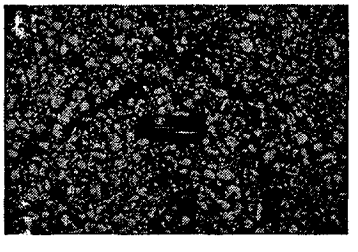
- Traffic

ADT: 33,000

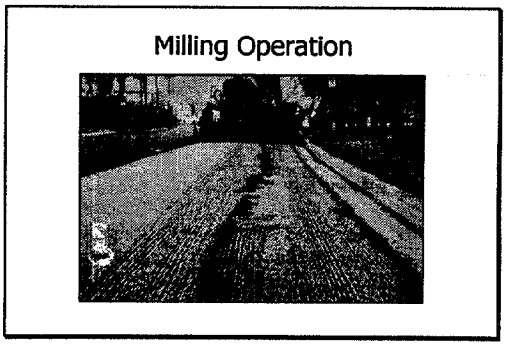
Truck Traffic: 10 %

Slide 6

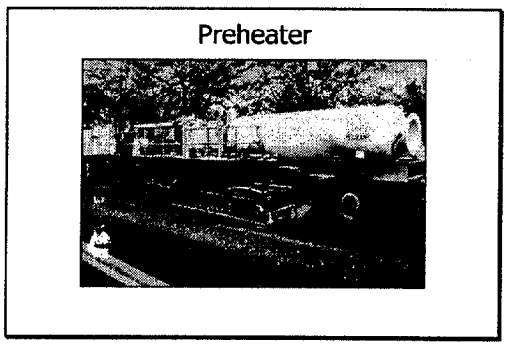
Cracks in Existing Pavement



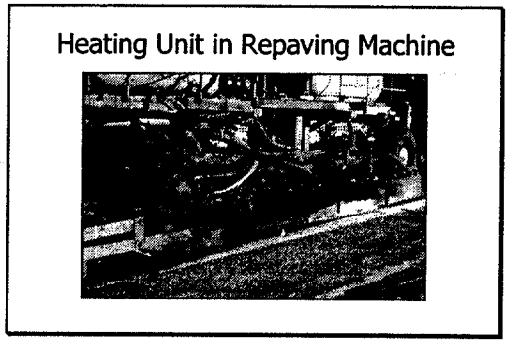
Slide 7



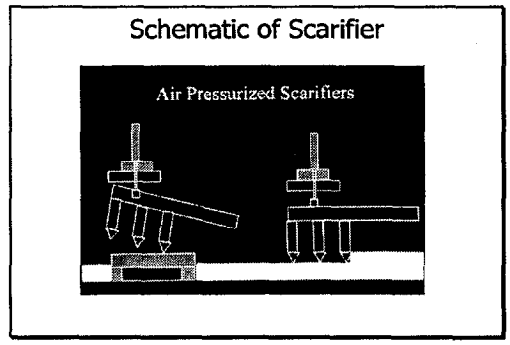

Slide 8



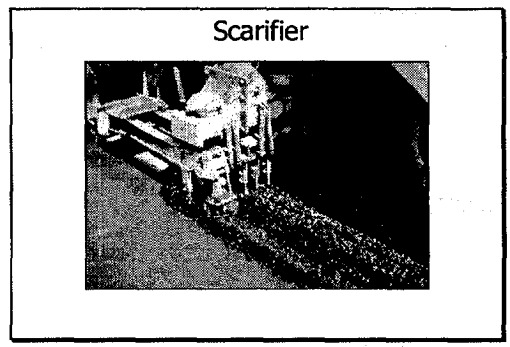

Slide 9



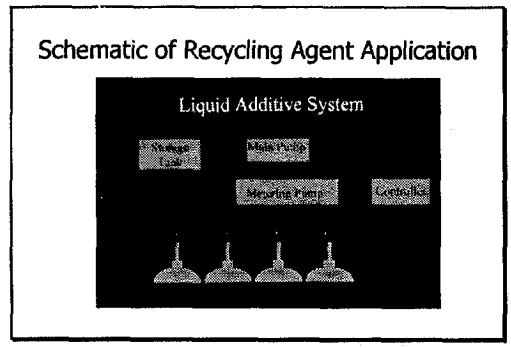
Slide 10




Slide 11




Slide 12



Slide 13

Spinning Cup for Recycling Agent

Slide 14

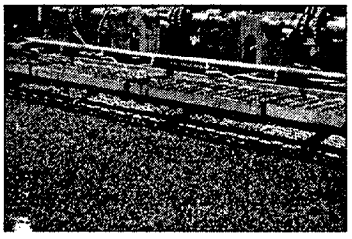
Mixing Operation

Slide 15

Close-up View of Recycled Material

Slide 16

HMA Overlay

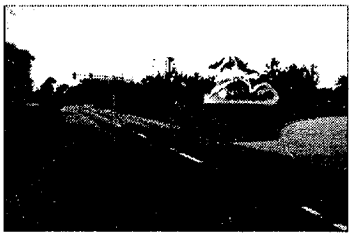


Slide 17

Recycling Operation

Slide 18

Recycled Pavement



Slide 19

## Cost of Recycling

- $3.44 per $m^2$
- Minimum Area of Recycling Required: 60,000 $m^2$

Slide 20

## Case History

HIR in Highway 3:14 and 3:16,
Canada
1993

Slide 21

## Existing Pavement

- AADT of 3,040
- 50-70 Cracks per km
- Distorted Transverse Cracks
- 2-14 mm rutting

Slide 22

## HIR

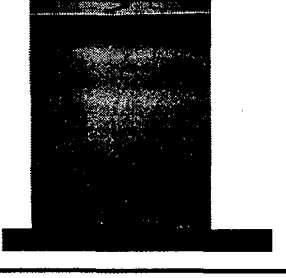
- HIR to a depth of 40 mm
- 0.3 % Recycling agent added
- 10 % blend sand added
- 75-Blow Marshall testing performed on recycled mix

Slide 23

## Schematic of Equipment

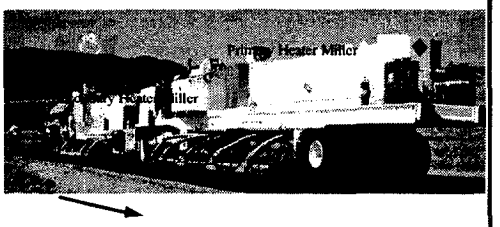
Slide 24

## Condition of Road Before Recycling



Slide 25

## Recycling Operation



Slide 26

## Condition after recycling

Slide 27

## Cost

| Cost | HIR | HMA Overlay |
|---|---|---|
| Cost per $m^2$ | $2.00 | $3.21 |
| Cost per Mg | $23.97 | $25.67 |
| Cost per km(2 lane) | $14,600 | $41,400 |

Slide 28

Remixing Process

City of Edmonton, Canada

1994

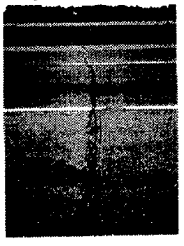
Slide 29

HIR

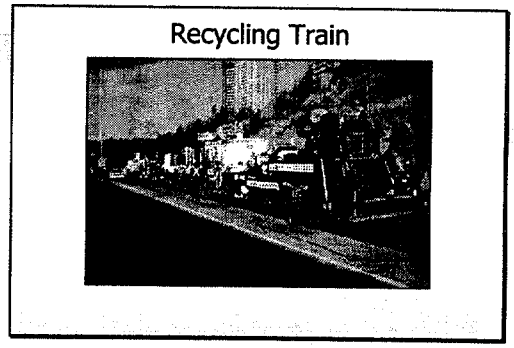
- HIR to a depth of 50 mm
- 0.15 - 0.20% recycling agent used
- 7% coated sand (2-3% asphalt content) mixed with existing HMA
- 75-Blow Marshall testing performed on recycled mix
- 137,600 sq. m of Recycling

Slide 30

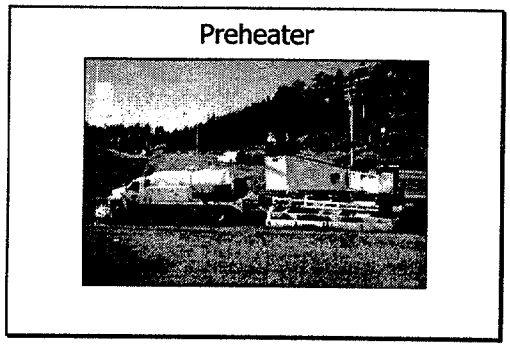
Existing Road Condition



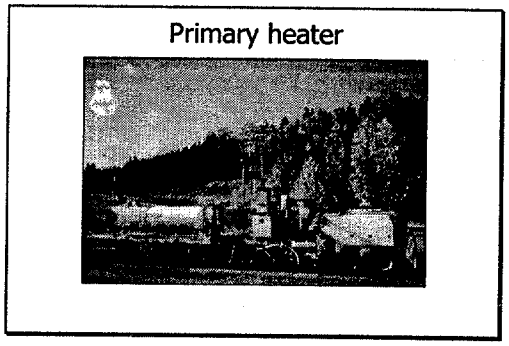
Slide 31




Slide 32




Slide 33



Slide 34

## Secondary heater miller with paver

Slide 35

## Road Before and After Recycling

Slide 36

## Cost of Recycling

- Total Cost: $ 262,701
- Cost per $m^2$: $ 5.01
- Estimated Cost of Conventional Technique:Remove and Replace:

  $ 6.60 -0 7.77 per $m^2$

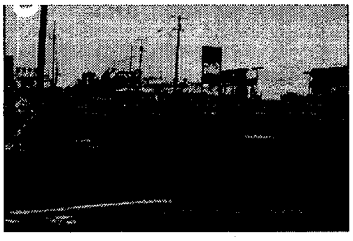
Slide 37

## HIR

- Effectively used to treat rutting at intersections
- City of Edmonton, Canada
- Method used: Remixing

Slide 38

## Intersection with rutting



Slide 39

## Recycling train at intersection

Slide 40

## Close-up View of Rutting at Intersection

Slide 41

## View of Intersection After Recycling

Slide 42

## Specifications for HIR

- Method specification
- End-result specification
- Combination of both recommended for HIR

Slide 43

## Quality Control(QC)/Quality Assurance (QA)

| ITEM | METHOD |
|---|---|
| Depth of Scarification | Measure depth |
| Application Rate of Recycling Agent | Calculate from quantity used |
| | Determine asphalt content before and after adding recycling agent |

Slide 44

## QC/QA (Continued)

| ITEM | METHOD |
|---|---|
| New Mixture Addition Rate | Calculate from the Quantity Used |
| Temperature of Mix Before Compaction | Measure |
| Properties of Asphalt Binder in Recycled Mix | Recover Asphalt by Abson or Rotovap Procedure and Test |

Slide 45

## SUMMARY

- HIR is Effective in Treating Distress
- HIR is Less Costly
- Cause of Distress Should be Ascertained Before HIR
- QC/QA Required

Slide 46

Hot In-Place Recycling (HIR)
Case Histories and QC/QA

???

Slide 1

Cold-Mix Asphalt Recycling
(Central Plant)
Construction Methods and
Equipment

Slide 2

## Cold Mix Recycling

- RAP and Reclaimed Aggregate (if any) Mixed with New Asphalt Binder and New Aggregate (if Needed) to Produce Cold. Recycled Mix Without Application of Heat
- Recycled Mix is Produced at a Central Plant Rather than In-Place.

Slide 3

## Steps Involved

- Removal of Existing Pavement
- Crushing and Stockpiling
- Mixing
- Laydown, Aeration and Compaction

Slide 4

## Steps Involved

- **Removal of Existing Pavement**
- Crushing and Stockpiling
- Mixing
- Laydown, Aeration and Compaction

Slide 5

## Removal of Existing Pavement

- Rip Existing Pavement and Crush and Size at Central Plant
- Rip, Break and Pulverize on Site
- Cold Milling

Slide 6

## Ripping Process

Slide 7

Milling with Truck Being Loaded with RAP

Slide 8

## Steps Involved

- Removal of Existing Pavement
- **Crushing and Stockpiling**
- Mixing
- Laydown, Aeration and Compaction

Slide 9

## Important Considerations

- Crush to Required Size
- Do not Permit Construction Equipment on Stockpiles

Slide 10

## RAP Stockpile

Slide 11

## Steps Involved

- Removal of Existing Pavement
- Crushing and Stockpiling
- **Mixing**
- Laydown, Aeration and Compaction

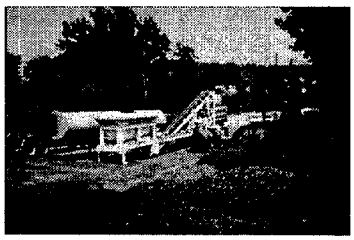
Slide 12

## Mixing

- Batch, Drum, or Continuous (Stabilization) Plants Used
- Control Feed Rate of Cold Bins
- Plants should have capability to Add Water and Asphalt Binder
- Continuous Plants Most Common

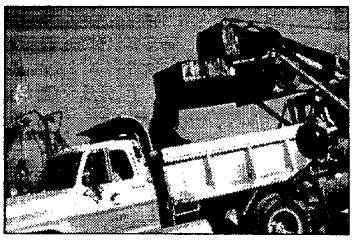
Slide 13

## Continuous Plant



Slide 14

Truck Being Loaded with Mix From Continuous Plant



Slide 15

## Mixing

- Do not Overmix
- Do not Undermix
- 100 % Coating of Recycled Mix Not Always Possible

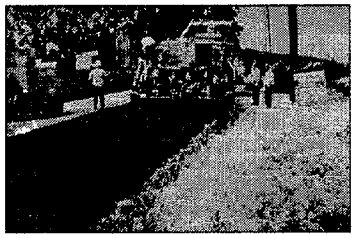
Slide 16

## Steps Involved

- Removal of Existing Pavement
- Crushing and Stockpiling
- Mixing
- **Laydown, Aeration and Compaction**

Slide 17

## Laydown and Compaction



Slide 18

## Laydown and Compaction

Slide 19

## Laydown and Compaction

Slide 20

## Aeration

- Required to Reduce Water and Volatile Content
- Required to Support the Compaction Equipment
- Use Multiple Lifts if Curing is a Problem

Slide 21

## Compaction

- Steel Wheel, Pneumatic-Tired or Vibratory Roller
- Use Heavy Weight, Pneumatic-Tired Roller for Breakdown
- Achieve Optimum Density

Slide 22

## Steel Wheel and Pneumatic-Tired Roller

Slide 23

## Compacted Cold Recycled Base

Slide 24

## Overlay

- HMA
- Double Surface Treatment
- Do not Place if Excessive Moisture in Cold Recycled Base
- Apply Fog Seal, if Necessary, before Opened to Traffic Prior to Overlay

Slide 25

## Project with HMA Overlay

Slide 26

## Summary

- Cold Mix Recycling can Rectify Reflection Cracking, Frictional Resistance, and Improve Ride Quality
- Procedure Involves Removal of Pavement Material, Crushing, Mixing and Laydown
- Aeration may be Required Before Compaction
- Wearing Surface Recommended

Slide 27

## Cold-Mix Asphalt Recycling (Central Plant) Construction Methods and Equipment

???

Slide 1

Cold Mix Asphalt Recycling
(In-Place) Construction Methods
and Equipment

Slide 2

## Cold In-Place Recycling

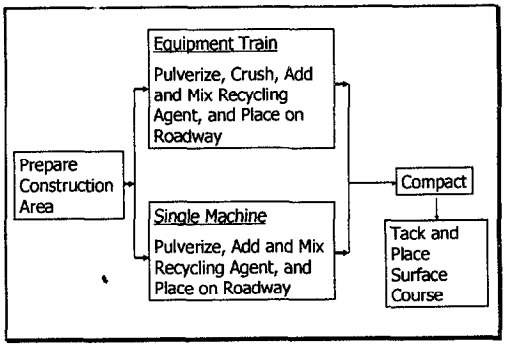
- Existing Pavement Materials Removed, Mixed with Virgin Materials and Reused In Place

Slide 3

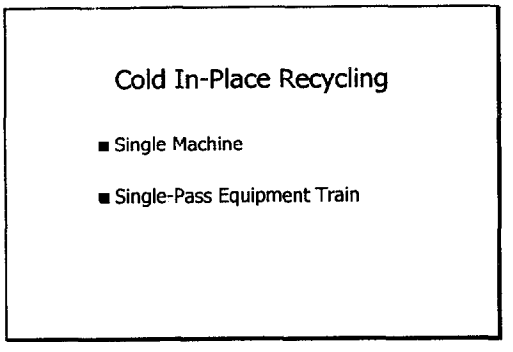
## Cold In-Place Recycling

| | |
|---|---|
| Partial Depth Recycling (50 to 100 mm) | Cold In-Place Recycling |
| Full Depth Recycling | Full Depth Reclamation |

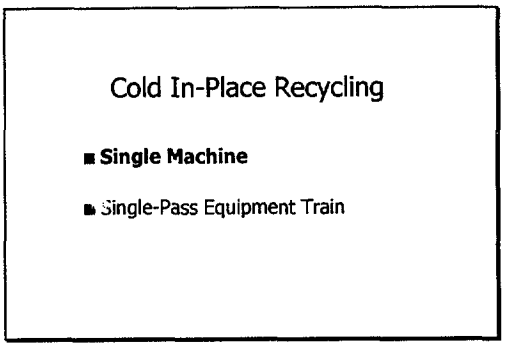
Slide 4




Slide 5




Slide 6



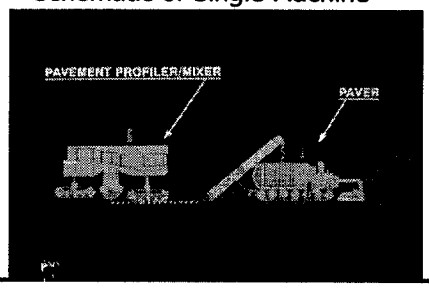
Slide 7

## Single Machine

- Milling Machine with Paver Mixer
- Breaks, Pulverizes, and Adds Recycling Agent in a Single Pass
- Virgin Aggregate, if Needed, Spread on Existing Surface
- Recycling Agent Added in Milling Chamber

Slide 8

## Schematic of Single Machine




Slide 9

## Single Machine

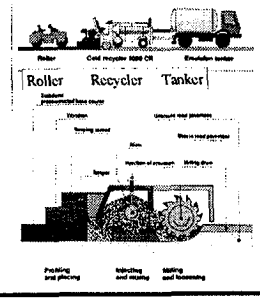
Slide 10

## Single Machine

- Single Machine with Emulsion Tanker
- Single Machine Mills, Injects Emulsion, Mixes, and lays down with Screed
- Recycling Agent Added on Milled Material

Slide 11

## Schematic of Single Machine




Slide 12

## Single Machine

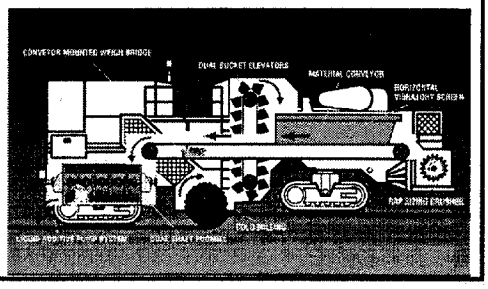
Slide 13

## Single Machine

- Single Machine with Emulsion Tanker and Paver
- Single Machine Mills Existing pavement, Adds Recycling Agent, and Deposits Material in a Windrow
- Paver Picks up Recycled Material and lays down with Screed

Slide 14

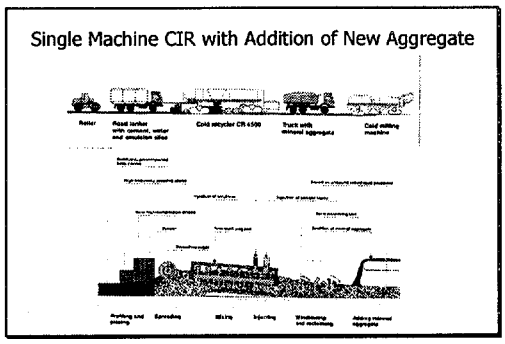
## Schematic of Single Machine



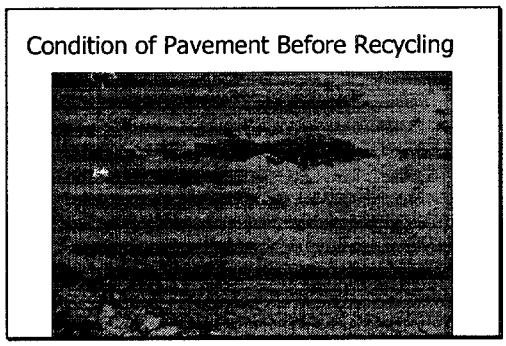
Slide 15

## Single Machine

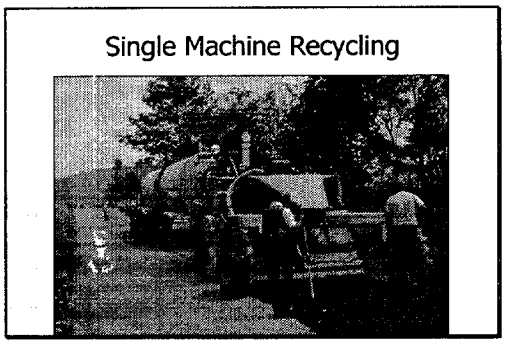
Slide 16




Slide 17




Slide 18



Slide 19

Condition of Pavement After Recycling

Slide 20

## Advantages

- High Production
- Simplicity

## Disadvantages

- Depth Limitation
- RAP Oversize

Slide 21

## Cold In-Place Recycling

- Single Equipment Machine
- **Single-Pass Equipment Train**

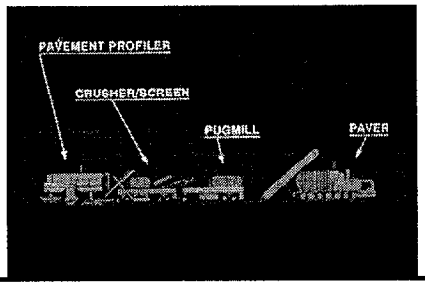
Slide 22

## Components of Train

- Cold Milling Machine
- Portable Crusher
- Travel-Plant Mixer
- Laydown Machine

Slide 23

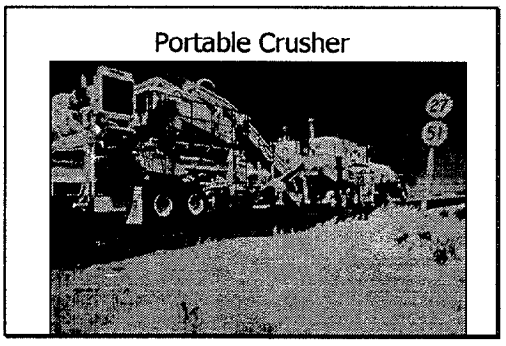
## Schematic of Single Pass Equipment Train



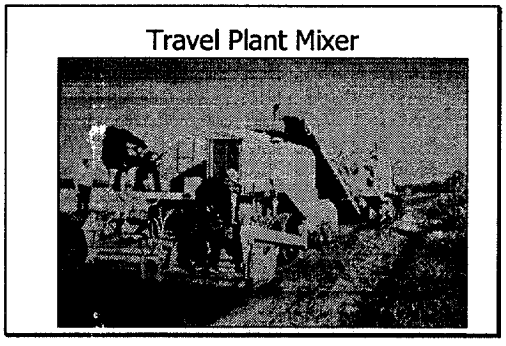

Slide 24

## Cold Milling Machine

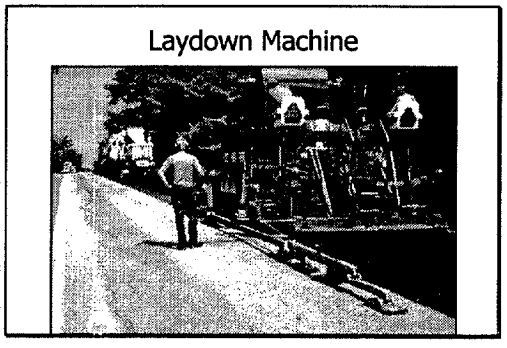
Slide 25



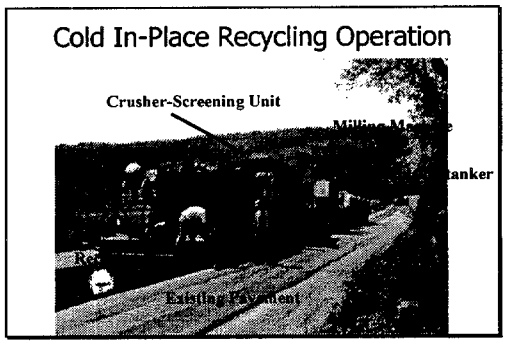

Slide 26




Slide 27

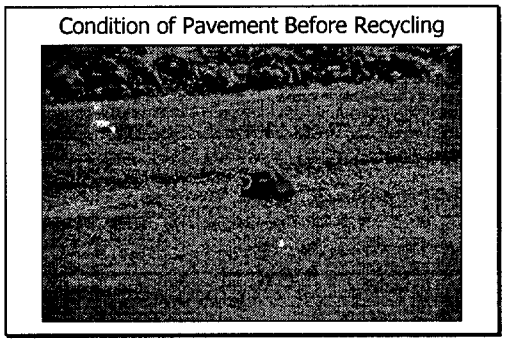


Slide 28



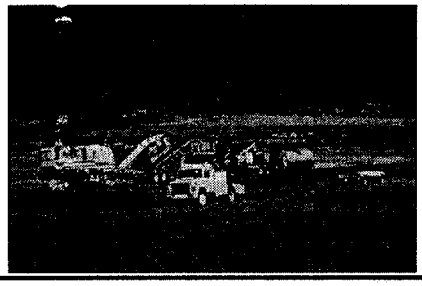

Slide 29


Slide 30



Slide 31

## Cold In-Place Recycling Operation



Slide 32

## Condition of Pavement After Recycling

Slide 33

## Curing and Compaction

- Curing or Aeration Needed to Reduce Water and Volatiles
- Delay Rolling or Blade the Mix
- Use Steel-Wheel, Pneumatic-Tired or Vibratory Rollers; Use Heavy Pneumatic-Tired Roller for Breakdown
- Achieve Optimum Compaction

Slide 34

## Application of Wearing Surface

- Additional Curing Needed to Avoid Moisture Retention
- Apply Fog Seal, if Necessary, Before Allowing Traffic
- Wearing Course: HMA Overlay or Double Surface Treatment

Slide 35

## Finished Job

Slide 36

## Summary

- Method can Eliminate Rutting, Cracking and Irregularities
- Can be Done by Single Machine or Equipment Train
- Mix May Require Aeration Before Compaction

Slide 37

Cold Mix Asphalt Recycling
(In-Place) Construction Methods
and Equipment

???

Slide 1

Cold-Mix Asphalt Recycling

Case Histories and QC/QA

Slide 2

Cold-Mix Asphalt Recycling

- Pulverization of Existing Pavement
- Sizing of RAP, if Desired
- Addition of Recycling Agent and Mixing
- Placement and Compaction

Slide 3

Case History

Traffic Route 208
Mercer County
Pennsylvania
1985

Slide 4

## Traffic Route 208

- Traffic:
  - ADT: 2,500
  - Truck Traffic: 10 %

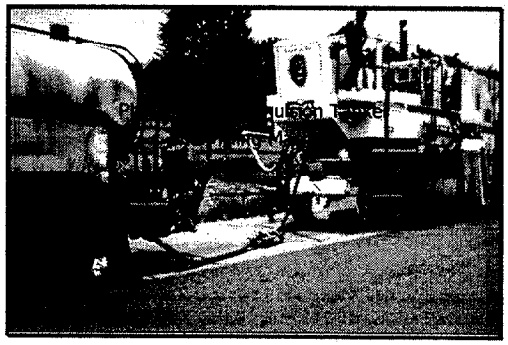
Slide 5

## Recycling Train

- Emulsion Tanker
- Milling Machine
- Crusher
- Mixer
- Paver

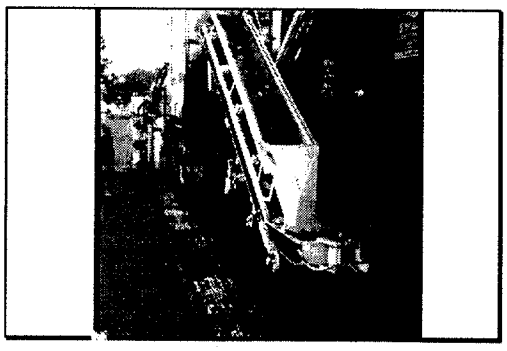
Slide 6

Slide 7

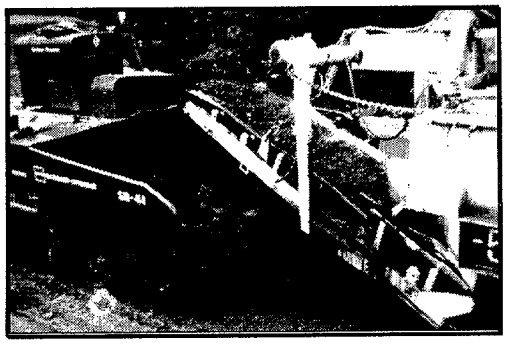


Slide 8

Slide 9



Slide 10



Slide 11

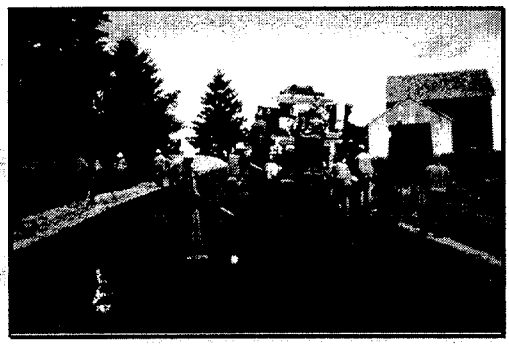
Slide 12

## Recycling Process

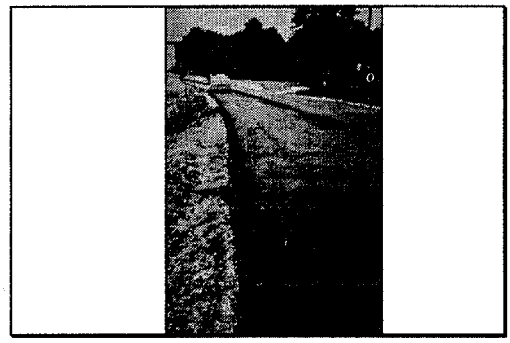
- No Pre-Mix Water Used
- CSS 1h Emulsion Diluted with 50% Water Used
- 3% CSS-1h by weight of RAP
- Vibratory and Pneumatic Tired Rollers Used
- 90 mm HMA Overlay over Recycled Base

Slide 13

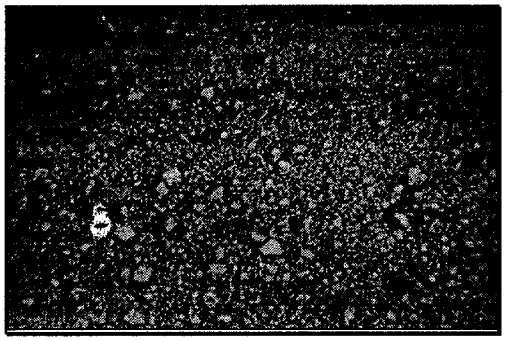
Slide 14



Slide 15



Slide 16



Slide 17

Slide 18

Case History

US 64
New Mexico
1984

Slide 19

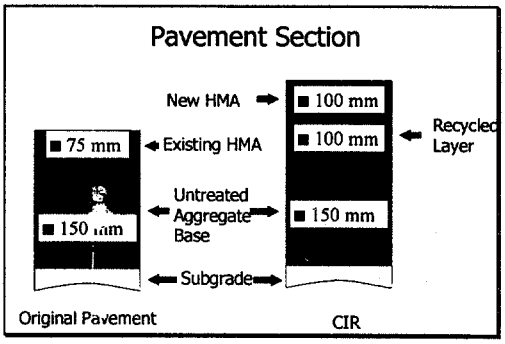
## US 64

- Traffic:

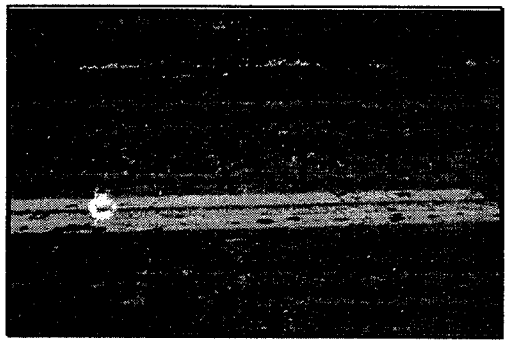
  AADT: 2,010

  Average Daily Load (80kNESWL): 113

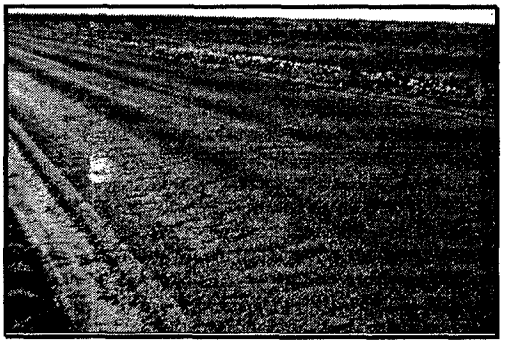
Slide 20



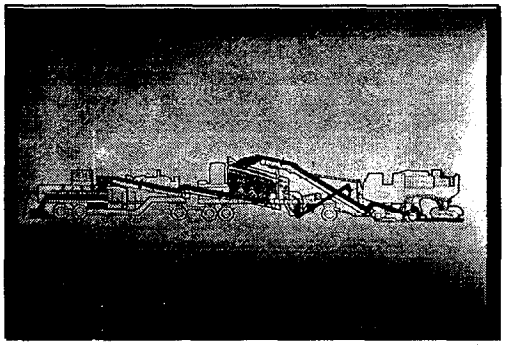

Slide 21



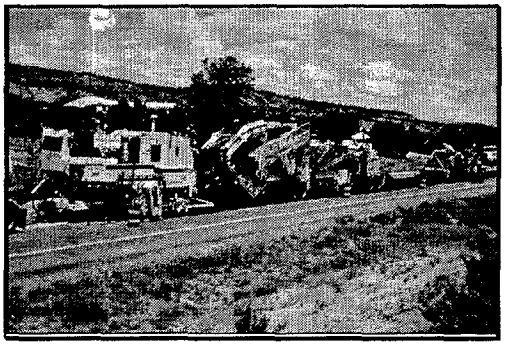
Slide 22



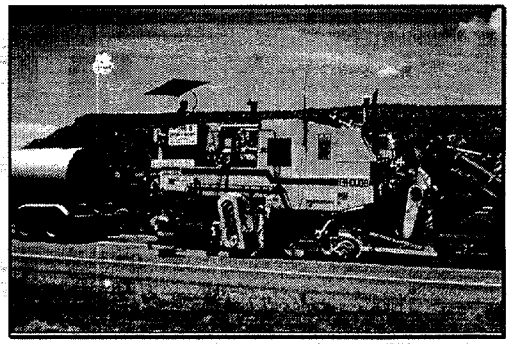
Slide 23



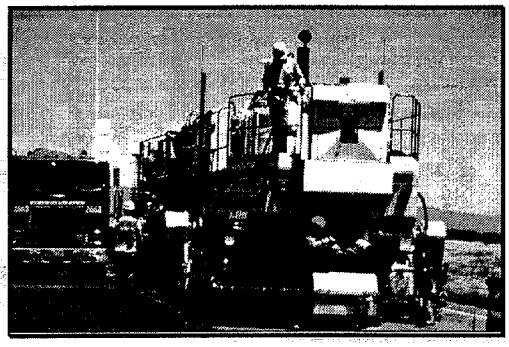
Slide 24



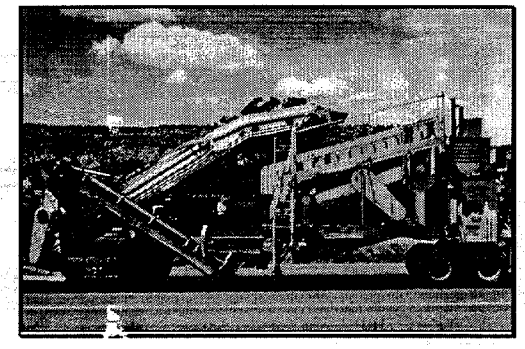
Slide 25



Slide 26

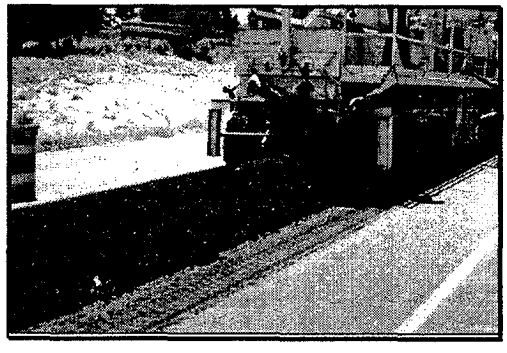


Slide 27

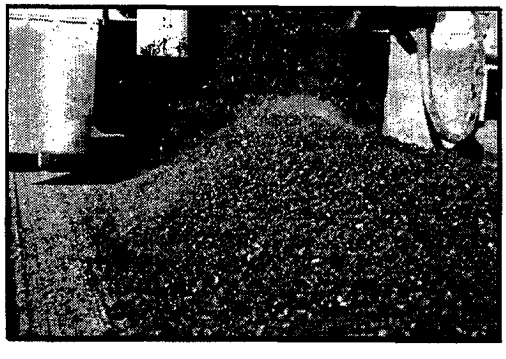


Slide 28

Slide 29



Slide 30

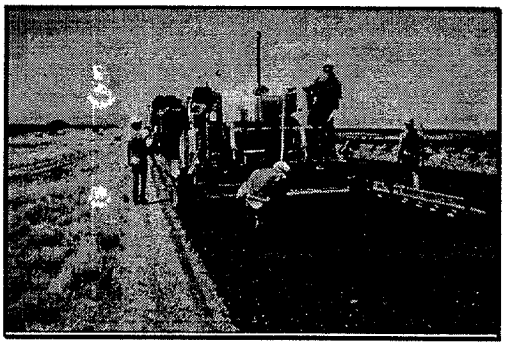


Slide 31

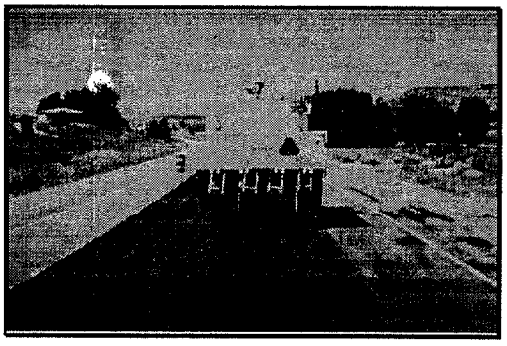
## Recycling

- Polymer Modified High Float Emulsion Used at a Rate of 1-3 Percent
- Depth of Recycling: 100 mm
- 100 mm HMA Overlay Used

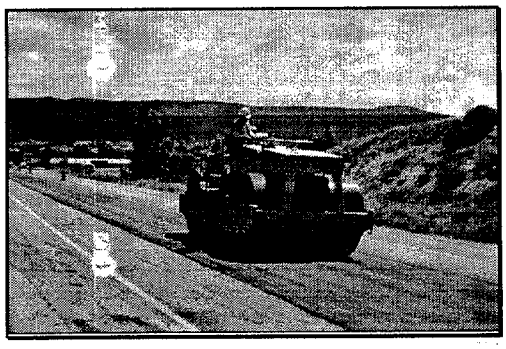
Slide 32



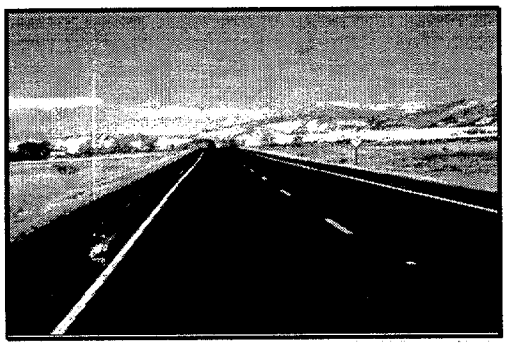
Slide 33



Slide 34



Slide 35



Slide 36

## Cost Comparison

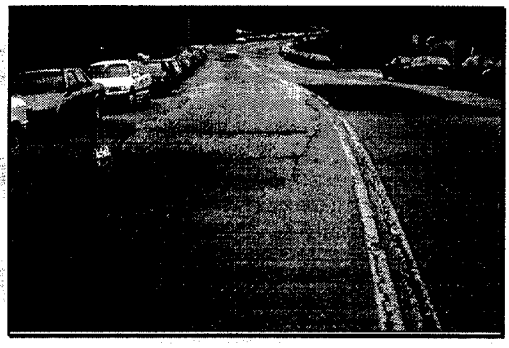
| Option | Initial Cost (per $m^2$) | Maintenance Cost (per $m^2$) | Total Cost (per $m^2$) |
|---|---|---|---|
| CIR | $5.75 | $0.13 | $5.88 |
| Mill and Overlay | $7.34 | $0.26 | $7.60 |
| Cost Savings | $1.90 | $0.13 | $2.03 |

Slide 37

Case History

Baltimore County, Maryland
1995

Slide 38

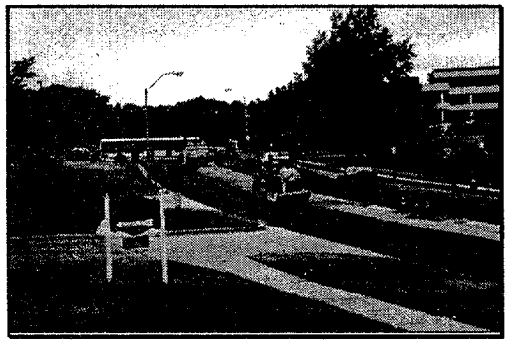


Slide 39

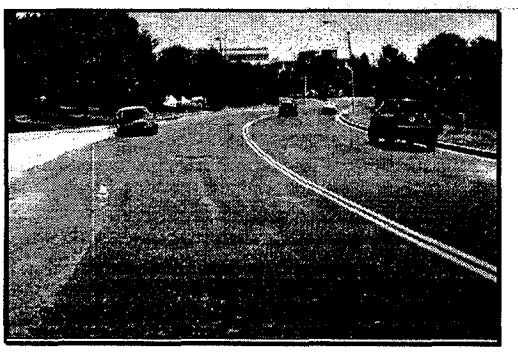
Slide 40

Slide 41

Slide 42



Slide 43



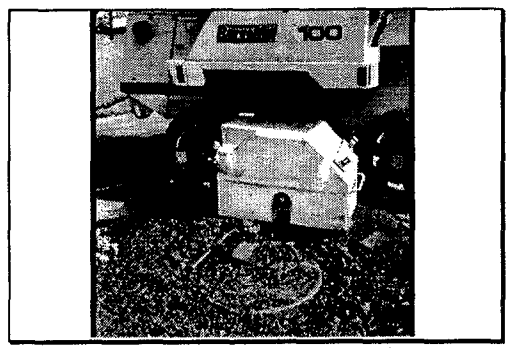
Slide 44


Slide 45

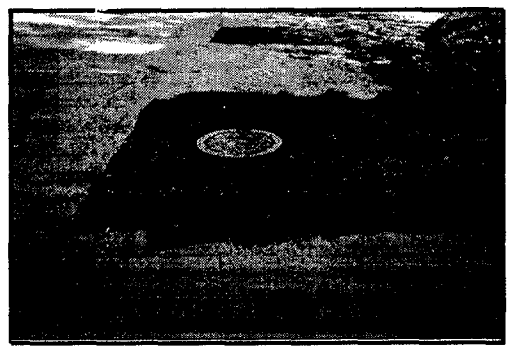
Recycling Around Utility

Slide 46

Slide 47




Slide 48



Slide 49

## Cold In-Place Recycling

- Specification
- Quality Control/Quality Assurance (QC/QA)

Slide 50

## Cold In-Place Recycling

- Specification
- Quality Control/Quality Assurance (QC/QA)

Slide 51

## Specification

- Combination of Method and End Result Specification Recommended
- Emphasize End Result to Encourage Innovation in Equipment and Construction Procedures

Slide 52

## Commonly Specified Items

- Depth of Pulverization
- Maximum RAP size
- Specification for Recycling Agent
- Specification for New Aggregate, if Used
- Tolerance for Amount of Recycling Agent
- Compacted Mat Density

Slide 53

## Cold In-Place Recycling

- Specification
- Quality Control/Quality Assurance (QC/QA)

Slide 54

## QC/QA Test Procedures

- Depth of Pulverization
  - Measure Against Unpulverized Pavement
  - Weigh pulverized Material from Known Area
- Re-Mix Water
  - Use Microwave Oven
- Recycling Agent Content
  - Use Extraction Method or
  - Use Ignition Method

Slide 55

## QC/QA Test Procedures (Continued)

- Recycled Mix Gradation
  - Use Extraction Method or
  - Use Ignition Method
- Compacted Mat Density
  - Use Nuclear Density Gauge
    - % of Theoretical Maximum Density or
    - % of Laboratory Density or
    - % of Control Strip Density

Slide 56

## Summary

- Cold-Mix Recycling can Treat Cracks Effectively
- In General, Emulsified Asphalt is Used as the Recycling Agent
- Double Seal Coat or HMA Overlay Recommended
- Important QC/QA Factors are Depth of Pulverization, Gradation of Material, Recycling Agent Content, and Compacted Density

Slide 57

## Cold-Mix Asphalt Recycling Case Histories and QC/QA

???

Slide 1

Full Depth Reclamation
Construction Methods
and Equipment

Slide 2

## Definition

Recycling Method Where All of Asphalt Pavement Section and a Predetermined Amount of Underlying Materials are Treated to Produce a Stabilized Base Course.

Slide 3

## Advantages

- Pavement Structure (Especially Poor Base) Improved Without Significantly Affecting Pavement Geometry
- Eliminates Ruts, Rough Areas, and Potholes and Restores Desired Profile
- Eliminates Alligator, Transverse, Longitudinal and Reflection Cracking
- Provides a Uniform Pavement Structure

Slide 4

## Advantages (continued)

- Frost Susceptibility may be Improved
- Low Production Cost
- Conservation of Materials and Energy
- No Air Quality Problems

Slide 5

## Main Steps

- Pulverize Existing Pavement
- Introduce Additive and Mix
- Shape the Mixed Material
- Compact
- Apply a Wearing Course

Slide 6

## Equipment

- Soil Stabilization Equipment and Different Variations of Oil Stabilization Equipment Are Used
- Blade Mixer
- Motor Grader
- Rotary Mixer

Slide 7

## In-Place Sizing and Mixing Operations

- Multiple-Step Sequence
- Two-Step Sequence
- Single Machine
- Single Pass Equipment Train

Slide 8

## In-Place Sizing and Mixing Operations

- **Multiple-Step Sequence**
- Two-Step Sequence
- Single Machine
- Single Pass Equipment Train

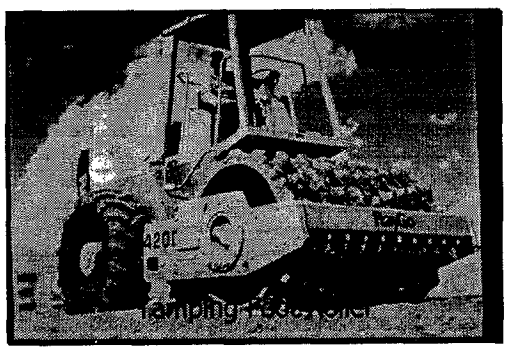
Slide 9

## Different Machines involved for Different Operations

- Ripping or Scarifying (Motor Grader or Dozer)
- Size Reduction (Sheep Foot Roller or Tamping Foot or Hammermill)
- Mixing (Rotary Mixer)

Slide 10

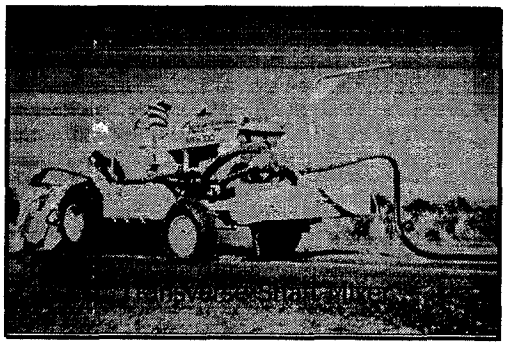
Slide 11



Slide 12

Slide 13

Slide 14



Slide 15

Slide 16

## Using Different Machines

- Advantage
  - Equipment Readily Available
- Disadvantages
  - Lack of Uniformity in Depth of Cut
  - Multiple Passes Required for Size Reduction
  - Low Production Rate
  - Traffic Control Problem

Slide 17

## In-Place Sizing and Mixing Operations

- Multiple-Step Sequence
- **Two-Step Sequence**
- Single Machine
- Single Pass Equipment Train

Slide 18

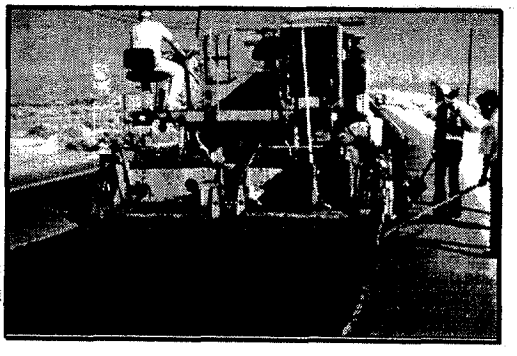
## Two-Step Sequence

STEP 1 - Cold Milling Machine Used

STEP 2 - Soil Stabilization Mixing Equipment or Traveling Mixer Used for Adding and Mixing Recycling Agent

Slide 19

Slide 20



Slide 21

## In-Place Sizing and Mixing Operations

- Multiple-Step Sequence
- Two-Step Sequence
- **Single Machine**
- Single Pass Equipment Train

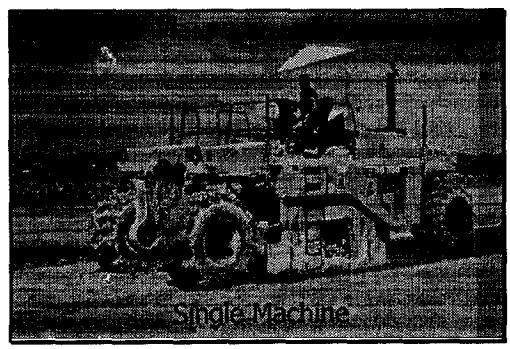
Slide 22

## Single Machine

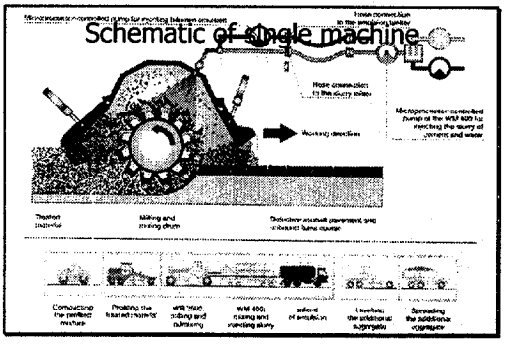
- Use Cold Milling Machines which can Break, Pulverize, and Add Recycling Agent in a Single Pass
- Advantages:
  - High Production Rate
- Disadvantages:
  - Possibility of Aggregate Oversize
  - Depth Limitation
  - Necessity of Specialized Equipment

Slide 23

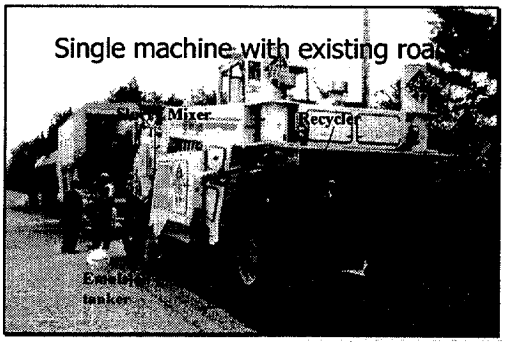
Slide 24



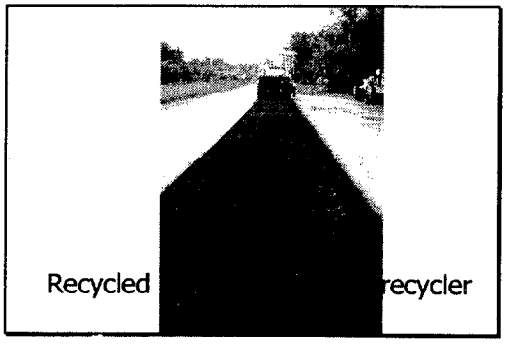
Slide 25



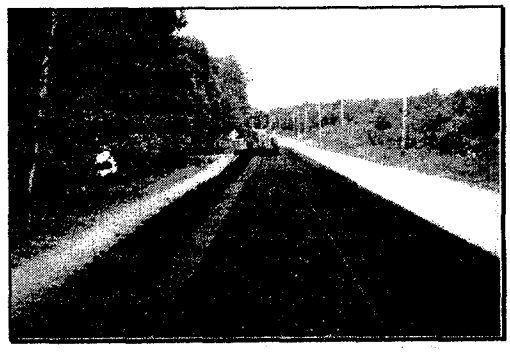

Slide 26




Slide 27



Slide 28



Slide 29

Slide 30

## In-Place Sizing and Mixing Operations

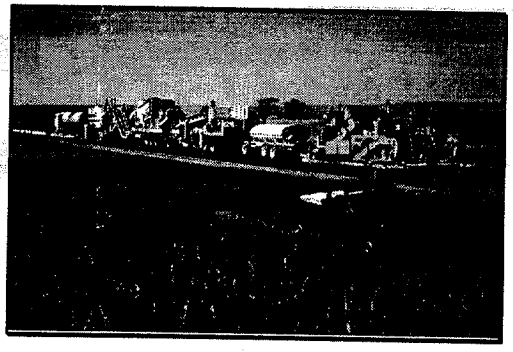
- Multiple-Step Sequence
- Two-Step Sequence
- Single Machine
- **Single Pass Equipment Train**

Slide 31

## Single-Pass Equipment Train

- Uses a Set of Equipment Required for Milling, Pulverizing, Mixing and Laydown Operation
- Advantages:
  - High Production Rate
  - Partial Depth Removal of Asphalt Layer is Possible
  - No Oversize Material is Produced
- Disadvantage:
  - Specialized Equipment is Needed

Slide 32



Slide 33

## Common Recycling Additives

- Emulsified Asphalts (MS and SS)
- Portland Cement
- Lime
- Fly Ash
- Calcium Chloride
- Foamed Asphalt

Slide 34

## Curing or Aeration

- To Reduce Water/Volatiles and Support Roller Weight
- Co.-.olled by Modifier Type, Water Content, Ambient Temperature, and Humidity

Slide 35

## Compaction

- Static Steel-Wheel Roller
- Pneumatic-Tired Roller
- Vibratory Roller
- Combination of Rollers

Slide 36

Slide 37

## Wearing Surface

- HMA Overlay or Double Seal Treatment
- Delay until Mix is Cured - No Excessive Moisture
- Apply Fog Seal, if Necessary, Before Opening to Traffic

Slide 38

## Summary

- FDR can Improve Pavement Structure, Restore Profile and Eliminate Cracks
- Steps Consist of Pulverization, Introduction of Additive, Shaping of Mixed Material and Compaction
- Proper Aeration of Mix Required

Slide 39

## Full Depth Reclamation Construction Methods and Equipment

???

Slide 1

Full Depth Reclamation
Case Histories
and QC/QA

Slide 2

## Definition

Recycling method where all of asphalt pavement section and a predetermined amount of underlying materials are treated to produce a stabilized base course.

Slide 3

## Case History

Mt. Wachusett Road
Princeton, Massachusetts
1991

Slide 4

## Mt. Wachusett Road, Princeton, Massachusetts

- Existing pavement 75 mm HMA over 150 mm macadam base (badly potholed)
- Full depth reclamation to a depth of 150 mm
- Liquid calcium chloride used as additive
- Overlay: 50 mm HMA binder course and 32 mm HMA wearing course

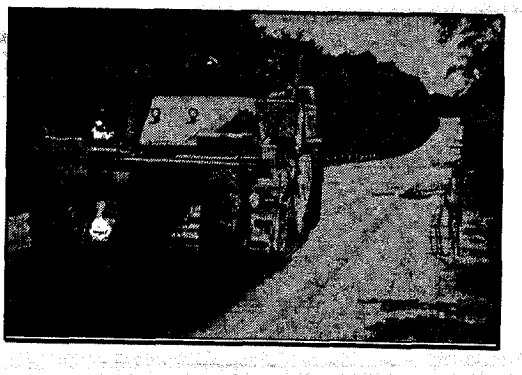
Slide 5

## Mt. Wachusett Road, Princeton, Massachusetts

- Road reclaimer used to pulverize (150 mm depth)
- Calcium chloride applied by a tanker spray bar (3.5 l/m$^2$)
- Material Pulverized second time to mix calcium chloride
- Grader used to shape the mixed material
- Vibratory roller used to compact reclaimed base

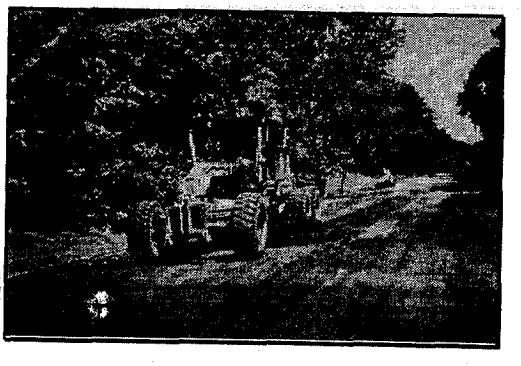
Slide 6

Slide 7

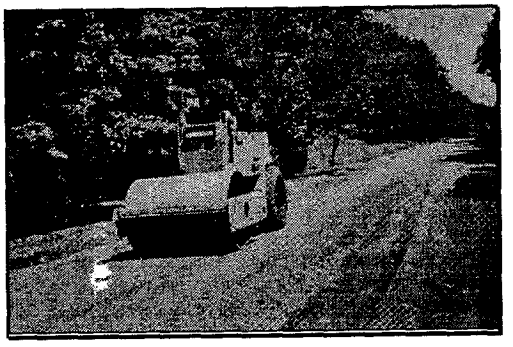


Slide 8

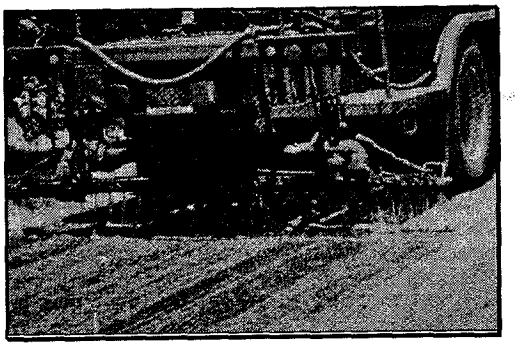
Slide 9



Slide 10



Slide 11



Slide 12

Slide 13

## Case History

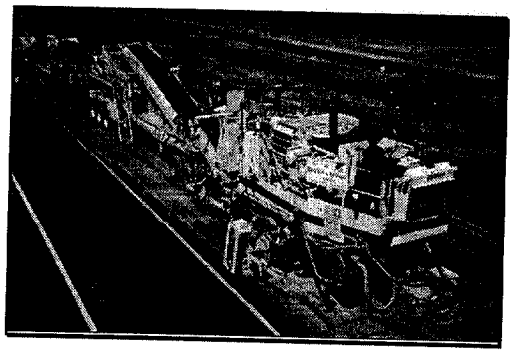
I-40, Amarillo, Texas

Slide 14

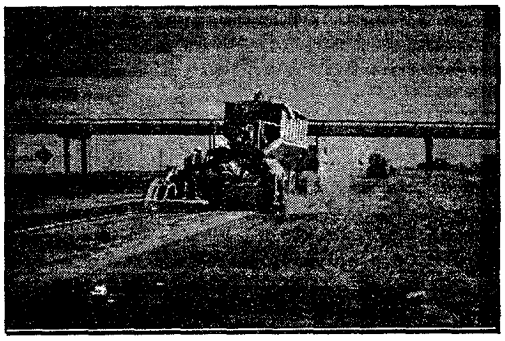
## I-40, Amarillo, Texas

- Existing pavement had cracks
- Full depth reclamation of 178 mm of HMA and 76 mm of existing base
- Existing material milled, pulverized, screened, and treated with cement and water to produce cement treated base
- MC-20 cutback asphalt used to prime surface

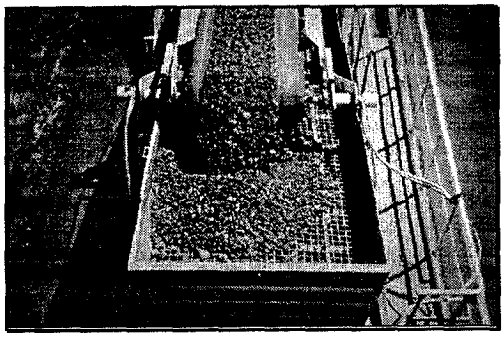
Slide 15



Slide 16

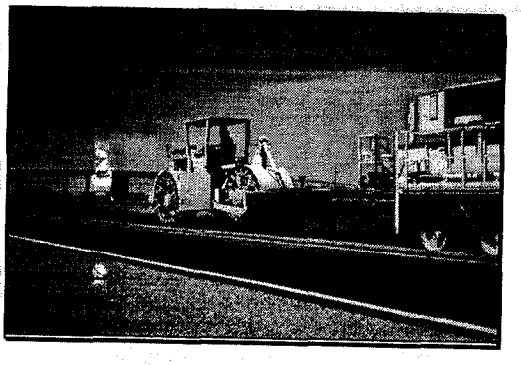


Slide 17



Slide 18

Slide 19



Slide 20

Slide 21

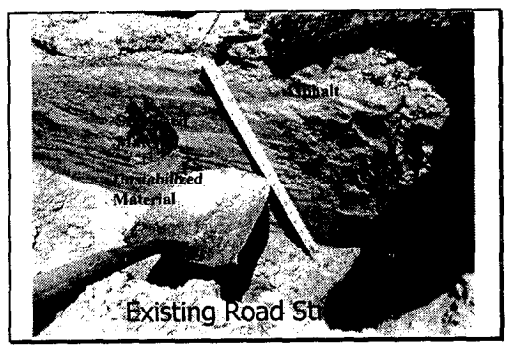
Slide 22

Case History

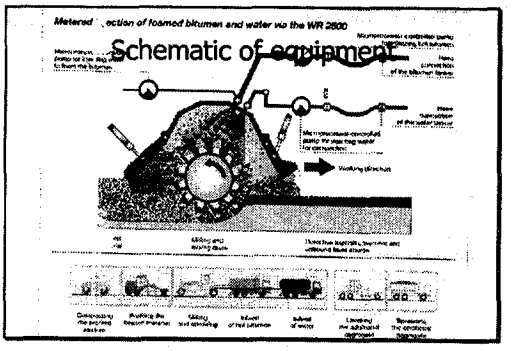
Mendota, California
1997

Slide 23


Slide 24



Slide 25




Slide 26

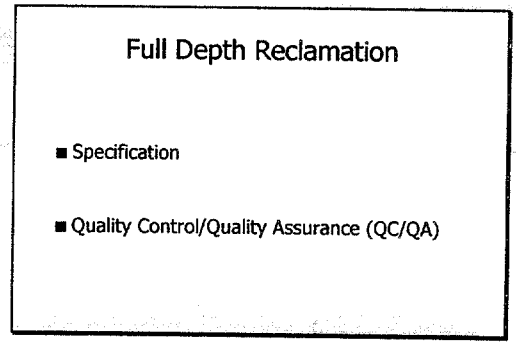

Slide 27

Slide 28

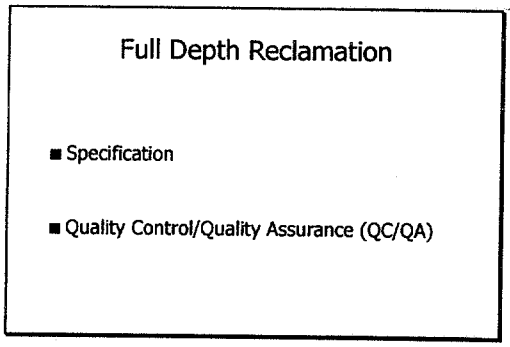

Slide 29


Slide 30

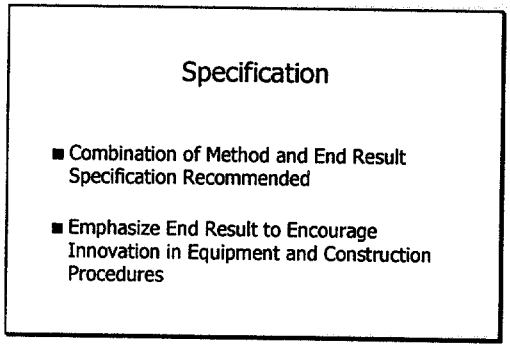
Slide 31




Slide 32




Slide 33



Slide 34

## Commonly Specified Items

- Depth of Pulverization
- Maximum RAP size
- Specification for Recycling Agent
- Specification for New Aggregate, if Used
- Tolerance for Amount of Recycling Agent
- Roller Weight and Sequence
- Compacted Mat Density

Slide 35

## Typical Specification

- 97 % of Pulverized Material Should Pass 50 Mm Sieve
- Compaction Should Be With Rubber Tired Roller Followed by Vibratory Steel Wheel Roller
- Minimum Weight of Rubber Tired Roller and Vibratory Roller Are 22.7 Mg and 7.3 Mg Respectively

Slide 36

## Full Depth Reclamation

- Specification
- Quality Control/Quality Assurance (QC/QA)

Slide 37

## QC/QA Test Procedures

- Depth of Pulverization
  - Measure Against Unpulverized Pavement
  - Weigh Pulverized Material from Known Area
- Re-Mix Water
  - Use Microwave Oven
- Recycling Agent Content
  - Use Extraction Method or
  - Use Ignition Method

Slide 38

## QC/QA Test Procedures (Continued)

- Recycled Mix Gradation
  - Use Extraction Method or
  - Use Ignition Method
- Compacted Mat Density
  - Use Nuclear Density Gauge
  - % of Theoretical Maximum Density or
  - % of Laboratory Density or
  - % of Control Strip Density

Slide 39

## Summary

- FDR can be Used Successfully Without Major Traffic Flow Interruption
- QC/QA Factors Include Aggregate Gradation, Stabilizer Content, Water Content, and Compacted Mat Density

Slide 40

Full Depth Reclamation
Case Histories
and QC/QA

???